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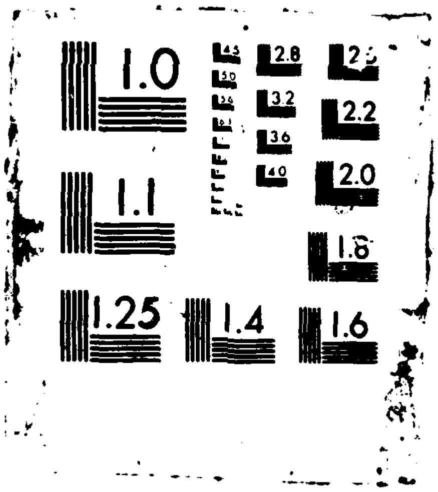
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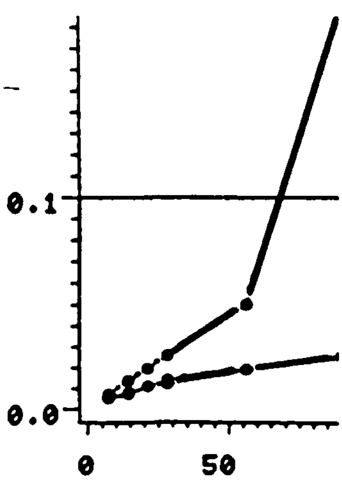

STRUCTURES LABORATORY

TECHNICAL REPORT SL-87-6

METHODS FOR CONTROLLING EFFECTS OF ALKALI-SILICA REACTION IN CONCRETE

by

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Structures Laboratory

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US ARMY ENGINEER WATERWAYS EXPERIMENT STATION

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This research project concerned methods of minimizing the effects of alkali-silica reaction in concrete. Ten pozzolans were tested to determine how they could most effectively be used to maximize reduction of expansion due to alkali-silica reaction when the pessimum amounts of opal or of reactive glassy igneous rock were used as aggregate with cements of several levels of alkali content. Three of these pozzolans (fly ash AD-505, fly ash AD-509, and natural pozzolan AD-518) were selected for further work and were used at selected levels of cement replacement with pessimum amounts of opal, glassy igneous rock, and an estimated pessimum for chert with each of two high-alkali cements. In general, use of these pozzolans at their optimum levels was an effective procedure as expansions of several tenths of a percent were usually reduced to a few hundredths. It was also found that some fly ashes when used at about 30 percent cement replacement level actually caused more expansion, especially with low-alkali cement. This is believed to be due to the additional water-soluble alkali provided by the fly ash to the system. ~~Work was done with~~

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different mineral fractions of a reactive granite gneiss plus the whole rock to identify the reactive constituent; it was concluded that the reactivity of the granite gneiss was due to strained quartz as a constituent mineral. Work with combinations of silica fume and calcium hydroxide with water showed the reactivity of the fume and identified a well crystallized calcium silicate (CSH-I) as the reaction product.

Preface

This project involved study of methods to minimize alkali-silica reaction; it was authorized and started in 1976. The project was performed by the Structures Laboratory (SL), US Army Engineer Waterways Experiment Station (WES) for the US Army Corps of Engineers (USACE) under Civil Works Investigational Study Work Unit 31294, "Minimize Alkali-Silica Reaction." Mr. Fred Anderson (DAEN-ECE-D) was the USACE Technical Monitor.

Mrs. Katharine Mather, formerly of SL, was Project Leader. All work was conducted under the supervision of Mr. John M. Scanlon, Chief, Concrete Technology Division (CTD), SL, and Mr. Bryant Mather, Chief, SL. This report was prepared by Mr. A. D. Buck. Others engaged in the work included Messrs. J. P. Burkes, G. S. Wong, Jay E. Rhoderick, and Ron Reinhold, CTD.

COL Allen F. Grum, USA, was the previous Director of WES. The present Commander and Director of WES is COL Dwayne G. Lee, CE. Dr. Robert W. Whalin is the Technical Director.

Contents

Conversion Factors, Non-SI to SI (Metric) Units of Measurement

Non-SI units of measurements used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
angstroms	0.1	nanometres
Fahrenheit degrees	5/9	Celsius degrees or kelvins*
inches	25.4	millimetres
pounds (force) per square inch	0.006894757	megapascals
pounds (mass)	0.4535924	kilograms
tons (2,000 pounds, mass)	907.1847	kilograms

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

METHODS FOR CONTROLLING EFFECTS OF ALKALI-SILICA REACTION IN CONCRETE

Introduction

1. The intent of this project was to search for practical controls for the effects of alkali-silica reaction in light of the evolving changes in cement composition brought about by changes in environmental controls. This research project was entitled "Minimize Alkali-Silica Reaction" and was conducted from 1976 through 1980. One portion of the work included determination of pessimum aggregate levels. The word "pessimum" is used to denote the most reactive amount of reactive material in an aggregate. It need not be and usually is not 100 percent of an aggregate.

Materials and Procedures

2. This project was conducted in several phases. The major effort consisted of testing 10 pozzolanic admixtures at two of three different levels with each of three cements of different alkali contents in mortar bars made with Pyrex glass. This was done to determine the most effective amount of pozzolan to effectively reduce expansion in this test. This testing was in general accordance with American Society for Testing and Materials (ASTM) C 441/CRD-C 257 (US Army Engineer Waterways Experiment Station (WES) 1949). This was followed by expansion testing of three reactive aggregates (Pyrex glass, opal, and glassy igneous rock) to establish their pessimum amounts with a low-alkali cement and two different high-alkali cements or with just the latter. Once the most effective amount of pozzolan and worst (pessimum) amount of reactive aggregate had been established, they were combined with two high-alkali cements in mortar bars to evaluate the control that was obtained by measurements of expansion in the mortar-bar test (ASTM C 227/CRD-C 123) (WES 1949). This was done using three reactive aggregates (chert, opal, and glassy igneous rock), two high-alkali cements, and three pozzolans (subbituminous coal fly ash, lignite fly ash, natural (pozzolan)). Chert was used instead of Pyrex glass for several reasons; these included the fact that Pyrex has its pessimum amount at 100 percent and is not a realistic aggregate. However, since no experimentation had been done with the chert, its pessimum amount was estimated. Another part of the work consisted of testing a slowly

reactive granite gneiss as sand, as coarse aggregate, and in separated mineral fractions to evaluate reactivity and to identify the reactive constituent of the rock. The final part of this work consisted of combining cement or calcium hydroxide (CH) with fly ash or the natural pozzolan or silica fume and water and monitoring changes by periodic determination of strength levels, by X-ray diffraction (XRD), and by scanning electron microscopy (SEM). Most of this latter effort centered on the reaction of a silica fume with CH. There was some characterization of materials as needed, especially of the reactive aggregates. The cements and pozzolans that were used had already been characterized by physical, chemical, and petrographic examination in other work.

3. The following materials were used as coarse aggregate or fine aggregate or both:

a. CL-3 G-1. For this work, 200 lb* of Pyrex glass cullet were received. Some of it was crushed into fine aggregate sizes.

b. CL-4 G-1. This was approximately 1,000 lb of chunks of Beltane opal. Some of it was crushed into fine aggregate sizes.

c. CL-28 MS-1. This was a reactive glassy igneous rock from a quarry near Jackson Hole, Wyoming.** Two shipments of chunks were received. The first was about 40 lb and the second was about 100 lb. All of the 40-lb sample and about half of the other shipment were combined and crushed into fine aggregate sizes.

d. CL-22 MS-1. This was fine aggregate processed from a local reactive chert gravel.

e. About 2 tons of reactive granite gneiss from Georgia were received in October 1976. A small amount of this was essentially 6-in. aggregate (CL-14 G-1(A)); the remainder was No. 67 rock (CL-14 G-1(B)) which is similar in size distribution to No. 4 to 3/4-in. material. As before, some of the No. 67 rock was crushed into fine aggregate sizes (CL-14 MS-1). Heavy media separation was used to divide some of this fine aggregate into three parts; one was a biotite mica concentration, another was a potassium feldspar concentration, and the third was a combined quartz and plagioclase feldspar concentration.

4. All of the reactive materials were washed after crushing and before use to remove fines. The washing of the mineral separations of the granite gneiss was mainly to remove all traces of heavy liquid.

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

** Identified as glassy andesite porphyry in a petrographic report by the US Army Engineer Division Laboratory, Missouri River (1975).

5. Two similar samples of limestone fine aggregate (CL-MS-28, CL-2 MS-1(3)) were used as needed to dilute the reactive aggregate (Pyrex, opal, glassy igneous rock, and chert) in a mortar mixture.

6. Petrographic examinations were made and physical data obtained for the aggregate samples as needed.

7. Four different portland cements, not counting repeat samples, were used in this project. They are identified below:

a. RC-688, RC-688(2). This was low-alkali cement (0.44, 0.37 percent as Na_2O) from Mississippi.

b. RC-720. This was high-alkali cement (0.79 percent as Na_2O) from Michigan. It was replaced by RC-725 when all of RC-720 had been used.

c. RC-725. This was high-alkali cement (0.78 percent as Na_2O) from Missouri.

d. RC-756, RC-756(2), RC-761. These were high-alkali (1.16, 1.31, and 1.07 percent as Na_2O) cements from New York. RC-761 was used for RC-756 during the course of this work due to lack of RC-756.

8. Eleven mineral admixtures were used. These were nine fly ashes (four lignite, three subbituminous coal, and two bituminous coal), one natural glass, and one silica fume, as identified below:

a. AD-505. Subbituminous coal fly ash from Missouri.

b. AD-506. Lignite fly ash from Texas.

c. AD-507. Subbituminous coal fly ash from Missouri.

d. AD-509. Lignite fly ash from North Dakota.

e. AD-510. Lignite fly ash from Minnesota.

f. AD-511. Bituminous coal fly ash from Georgia.

g. AD-512. Subbituminous coal fly ash from Iowa.

h. AD-513. Lignite fly ash from Colorado.

i. AD-570. Bituminous coal fly ash from Mississippi.

j. AD-518. Natural glass pozzolan from California.

k. AD-536, AD-536(2). Silica fume from Alabama.

9. Standard chemical and physical tests were made on all 4 cements plus repeat shipments and 11 admixtures. In addition, petrographic methods were used to identify crystalline phases in these materials. For the cements, this included examinations by XRD on the whole cement, on the insoluble residue after treatment with maleic acid, and on this insoluble residue after treatment with ammonium chloride. The latter two examinations were not made

on all of the cements. Treatment with maleic acid removes silicate phases; treatment with ammonium chloride removes sulfate phases. Examination of XRD patterns made after these chemical treatments is simplified and comparison between patterns of the same material before and after such treatment can assist in making correct identifications. The petrographic methods that were used also included examination of materials with a stereomicroscope, examination of grain immersion mounts and of thin sections with a polarizing microscope, and examination of materials with a scanning electron microscope.

10. All of the admixtures except the AD-570 ash were used at a 30 percent solid volume replacement level with low-alkali cement RC-688, with moderately high-alkali cement RC-720, and with high-alkali cement RC-756; length-change expansion was measured at 14 days and compared with similar data for bars made with these cements without any admixture. The reactive aggregate was the Pyrex glass. This testing procedure is essentially as described in ASTM C 441/CRD-C 257 (WES 1949) except for the use of other than the specified 25 percent admixture replacement by solid volume. The general intent was to calculate reductions in expansion for each admixture compared to its corresponding control mixture. If the reduction was 75 percent or more, the mixture was repeated using 25 percent admixture by solid volume replacement of cement. If the reduction was less than 75 percent, the mixture would be repeated using 50 percent replacement. In general, this was done with exceptions or modifications as needed. It was necessary to change from RC-720 to RC-725, a cement of similar alkali content, for the second phase because all of RC-720 had already been used. The amount of silica fume was reduced to 15 percent replacement because bars containing 30 percent fume shrank instead of expanding. Reduction in expansion data were later used to estimate the amount of admixture needed to obtain 75 percent reduction in expansion. This was done by plotting these data and interpolating or extrapolating as required to obtain these values.

11. The next step was to determine pessimum amounts of reactive material (Pyrex glass, opal, and glassy igneous rock) by using different amounts of these materials in the fine aggregate in mortar and determining expansion of mortar bars using the same test method as before for Pyrex glass. The reactive material was blended with limestone fine aggregate as needed. This was done for Pyrex glass and opal using RC-688 or RC-688(2), RC-725, and RC-756 or RC-761 (used to replace the exhausted supply of RC-756). The same procedures

were used with the glassy igneous rock using cements RC-725 and RC-756(2), but test method ASTM C 227/CRD-C 123 (WES 1949) was used instead of ASTM C 441/ CRD-C 257 (WES 1949). When the fine aggregate for mortar was to be a blend of limestone and reactive material, the reactive material used consisted of equal portions by mass of three sieve fractions: 2.36-1.18mm, 1.18mm-600μm, and 600μm-300μm (No. 8-No. 16; No. 16-No. 30; No. 30-No. 50, respectively).

12. Using the preceding work as a basis for choosing the most effective amount of admixture to reduce expansion due to alkali-silica reaction and the worst (pessimum) amount of aggregate to obtain maximum expansion by the same reaction, mortar mixtures were made and tested by ASTM C 227/CRD-C 123 (WES 1949) using such combinations to determine the control that was obtained. Fly ashes AD-505 (subbituminous) and AD-509 (lignite) were used to represent the ashes and AD-518 was used to represent a natural pozzolan. Moderately high-alkali RC-725 and high-alkali RC-756(2) cements were used. The reactive aggregates were opal, glassy igneous rock, and chert produced by crushing chert gravel. As indicated earlier, it was decided not to use the Pyrex glass. Therefore, a pessimum level for the chert was estimated since no work had been done to determine this value. The reactive rocks were distributed equally in the No. 16, 30, 50, and 100 sieves but no No. 8 size material was used. This inclusion of the smaller size in this work and not in the work to determine pessimum amounts of aggregate was necessary to compensate for some chert contamination of the limestone.

13. A different phase of the project work was done on the slowly reactive granite gneiss. Some of the coarse aggregate was crushed into fine aggregate sizes. A concrete mixture was made using this rock as coarse and fine aggregate. Compressive strength data for this mixture were obtained through 1 year. Length changes for specimens stored in a moist environment at 100° and 140° F were measured for 32 months. Mortar bars were made with the fine aggregate and measured for length changes under the same conditions as above for 30 months; the compressive strengths of 2- by 2- by 2-in. mortar cubes from this mixture were tested through 1 year.

14. The four major mineral phases in the reactive granite gneiss were separated into concentrations of biotite mica, potassium feldspar, and combined quartz and plagioclase by density separation of fine aggregate using a heavy liquid. Quartz and plagioclase were left combined because their densities were too close to permit a reasonable separation. The intent was to

determine which phase or phases were responsible for the reactivity of the rock. Since this effort resulted in small amounts and sizes of these concentrations, the amount of work that could be done was limited. Three normal size mortar bars (1 by 1 by 11-1/4 in.) were made with the mica concentration and three with the quartz-plagioclase concentration using only the 600-, 300-, and 150-μm (No. 30, 50, 100) sieves,* as these were all that were available; high-alkali cement RC-756(2) was used. One bar of each set was stored at 100° F with the other two bars kept at 140° F; these were measured for length changes periodically for 27 months. There was not enough of the potassium feldspar concentration to make normal size bars. Therefore, six small bars (1/2 by 1/2 by 3-1/2 in.) were made as above from each of the three mineral concentrations and half were tested for length changes at each of the same two temperatures for 1 year. Molds and containers to make these smaller bars were provided by the courtesy of Mr. Robert S. Barneyback, Jr., then at Purdue University.

15. The third and final phase of this project was to follow the strength development and composition of hydration products with time of cement and pozzolan or hydrated lime (CH) and pozzolan-paste mixtures. Materials were low-alkali cement RC-688(2) or CH with bituminous coal fly ash AD-511, natural pozzolan AD-518, and silica fume AD-536(2). Early combinations were one part cement or CH with two parts pozzolan; later the ratios were one to one and the water contents were changed. Curing was usually at room temperature for 24 hr and at 100° F thereafter. Composition was determined by periodic monitoring by XRD and SEM. After these early efforts, most mixtures that were made were CH and silica fume due to the unusual activity of this material; flow was usually between 95 to 110 percent. Adequate consolidation of paste specimens made with the fume was a continual problem due to the unusual fineness of this material. The final work in this phase was to make CH and fume mixtures and CH with bituminous fly ash AD-570 mixtures to have lime-to-silica (CaO/SiO_2, C/S) ratios of about 1 to 2; testing was as before.

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* About 30 percent retained on the 600-μm sieve, 34 percent on the 300-μm sieve, and 36 percent on the 150-μm sieve.

Results

16. Chemical and physical analytical data for the cements and the mineral admixtures that were used are shown in Tables 1 through 7 and 8 through 19, respectively; petrographic data for these materials are given in Reinhold et al. (1986). The work done to determine the most effective amount of 10 of these pozzolans in reducing expansion was described earlier. The actual expansion data are shown for low-alkali cement RC-688 in Table 20, moderate high-alkali cement RC-720 or RC-725 in Table 21, and high-alkali cement RC-756 in Table 22. These include initial mixtures with 30 percent pozzolan plus mixtures with 25 or 50 percent pozzolan plus the 15 percent silica fume. The data are generally self-explanatory. However, the behavior of three of the four lignite ashes should be noted. They were the only 3 (AD-509, AD-510, AD-513) of the 10 pozzolans that permitted more than 0.1 percent expansion when combined with low-alkali cement. As shown in Table 23, which is the calculation of reduction in expansion obtained with these pozzolans, these three actually encouraged expansion at the 30 percent level with the low-alkali cement. AD-510 also did this with moderate high-alkali cement RC-720 at the 30 percent level. Ash AD-510 was always found to be unusual without specific recognition of why this was so. Data for ashes AD-509, AD-510, and AD-513 (Tables 11, 12, and 15, respectively) show the following alkali contents:

	Percent Alkali as Na_2O			
Ashes	Water Soluble	Available	Acid Soluble	Total
AD-509	0.39	1.63	1.69	5.16
AD-510	0.66	2.55	2.67	3.54
AD-513	0.01	0.65	0.85	1.65

The total alkali content of low-alkali cement RC-688 is 0.44 percent expressed as Na_2O. It appears that use of AD-509 and AD-510 and perhaps AD-513 may have added as much alkali for reaction as was removed by replacing 30 percent of the cement, especially with the low-alkali cement.

17. Ashes AD-505 and AD-509 and the natural pozzolan AD-518 were later selected for further work. The foregoing data indicated most effective amounts by solid volume of each to inhibit expansion as follows:

Subbituminous Coal Fly Ash AD-505

30 percent with cement RC-725
50 percent with cement RC-756(2)

Lignite Fly Ash AD-509

50 percent with cement RC-725
60 percent with cement RC-756(2)

Natural Pozzolan AD-518

10 percent with either cement

This indication that large amounts of pozzolan would be needed to reduce expansion to an acceptable level had also been found by Pepper and Mather (1959). The set of three bars made with high-alkali cement RC-715 without pozzolan had expansions at 14 days of 0.374, 0.323, and 0.382 for an average of 0.360 percent.

18. The next part of this work was done to find pessimum amounts of reactive aggregates. The expansion data in Tables 24, 25, and 26 for Pyrex glass aggregate clearly show expansion always increases with amount, so its pessimum is 100 percent with each of three different cements.

19. Data for Beltane opal (CL-4 G-1) at the 2-, 4-, 6-, and 100-percent levels with cement RC-688 are shown in Table 27. Data for Beltane opal at the 1-, 2-, 4-, 6-, and 100-percent levels with cement RC-725 are shown in Table 28. Table 29 presents the data for Beltane opal at the 1-, 2-, 4-, 6-, and 100-percent levels with RC-756 or RC-761. XRD examination of crushed opal representative of that used in mortar bars indicated it was composed of:

Mineral	Relative Amount
Low temperature disordered alpha tridymite	Major
Quartz	Moderate
High-temperature tridymite	Minor
High- and low-temperature cristobalite	Minor

There was probably also some amorphous material. Similar work with a separate hand sample showed the above composition plus the presence of weak XRD peaks at 5.8 and 5.0 Å. Robert Barneyback, then at Purdue University, suggested these might be due to alunite, which is a hydrated potassium aluminum sulfate mineral. The chemical analyses of the composite sample and of the hand sample in Table 30 show a much higher sulfate level for the hand sample. It was concluded that there was some alunite in the hand sample but not in the rock used for mortar bars.

20. Expansion data for glassy igneous rock (CL-28 MS-1) at the 3-, 6-, 12-, and 100-percent levels in mortar bars with cement RC-725 are shown in Table 31. Similar data at the 5-, 10-, 20-, 40-, and 100-percent levels with cement RC-756(2) are shown in Table 32. These tests were made in accordance with ASTM C 227/CRD-C 123 (WES 1949) instead of ASTM C 441/CRD-C 257 (WES 1949), but this change should not be significant for the purpose of this work. XRD examination of both shipments of this rock showed crystalline phases to be tridymite, a 14-Å clay, plagioclase feldspar, pyroxene, magnetite, and hematite for the second shipment only, all in minor amounts. Examination of thin sections showed the rock to consist largely of a ground mass of devitrified glass with recognizable phenocrysts of some of the above phases; hypersthene, a pyroxene, was recognized as one of the pyroxenes by its pleochroism. Based on these examinations, the two shipments were combined as described and processed into fine aggregate. A chemical analysis of the fine aggregate was made and is shown in Table 33. The total alkali in this rock expressed as Na_2O is 5.04 percent calculated from the data for Na_2O and K_2O in the average column in this table. Separate analysis to determine the amount of water-soluble alkali in the rock was also done. Twenty grams of the rock were added to 200 ml of water in a flask. The flask was shaken for 10 min, and the solution filtered through a Buchner funnel which contained a filter paper. The filtrate was then diluted to 500 ml, and the Na_2O and K_2O determined by atomic absorption spectrophotometer (AA). The results are:

Water-soluble Na_2O - 0.002 percent

Water-soluble K_2O - 0.006 percent

Total water-soluble alkali, as Na_2O - 0.007 percent

This showed that most of the alkali was not water soluble.

21. Examination of the foregoing data for the three reactive aggregates indicated the following:

a. The pessimum amount was 100 percent for the Pyrex glass with all of the three cements used. As indicated before, it was decided not to use this material in the next part of this work.

b. The pessimum amount for the Beltane opal was about 1 percent or less with low-alkali cement RC-688, 1.5 percent with moderate high-alkali cement RC-725, and 3 percent with high-alkali cements RC-756 or RC-761; RC-756(2) was used in the next work because the supplies of RC-756 and RC-761 were exhausted.

c. The pessimum amount for the glassy igneous rock was 9 percent with moderate high-alkali cement RC-725 and 30 percent with high-alkali cement RC-756(2).

22. The physical properties of these reactive aggregates were not obtained since they were not needed to make mortars. The two limestone fine aggregates that were combined to dilute the reactive aggregates had the following properties:

	Absorption percent	Relative Density
CRD-MS-28	0.6	2.71
CRD-2 MS-1(3)	0.5	2.72

23. Tables 34 through 39 show the expansion data obtained when what were intended to be the most effective amounts of three pozzolans or no pozzolan (control mixture) were combined with intended pessimum amounts of three different reactive aggregates with each of two high-alkali cements. The data in Tables 34 and 35 indicate that the estimated pessimum of 80 percent for the chert was too high; therefore, no further attention will be paid to these data.

24. Since the no-pozzolan condition in Tables 36 through 39 represents the interpolation of reactive aggregate amounts from Tables 28 and 29 for the opal and Tables 31 and 32 for the glassy igneous rock, it is possible to determine by inspection of the data whether pessimum amounts were actually used. By this comparison the pessimum amounts look good for the 3-percent opal and both levels of glassy igneous rock. Visual interpolation from Table 28 at 56 days indicates expansion should be about 0.1 percent for 1.5 percent opal with cement RC-725. Since it was actually about half this

amount (Table 36), a batching error in the amount of opal used probably occurred since a separate remake of mortar using cement RC-725 and 1.5 percent opal did show the expansion expected. In any case, less attention should be paid in this table to the effect of pozzolan.

25. The use of 30 or 50 percent of ash AD-505 and of 50 or 60 percent of ash AD-509 through 105 to 113 days of testing (Tables 37, 38, and 39) seems quite effective as expansions of about 0.17 to 0.45 percent in the control mixtures without a pozzolan were all reduced to about 0.01 to 0.02 percent.

26. An extrapolated value for the most effective amount of natural pozzolan AD-518 from the mixtures that contained 30 and 25 percent of it was 10 percent. However, inspection of the data for those mixtures containing this amount of AD-518 (Tables 36 through 39) shows that 10 percent was not effective in reducing expansion. Six additional mortar mixtures containing 0, 5, 10, 20, 25, and 30 percent of AD-518 were made with high-alkali cement RC-756(2) and 3 percent opal and tested for length changes out to about 90 days (only 29 days for the mixture with 25 percent AD-518) (Table 40). These verify that 10 percent or less of this material is not effective in reducing expansion and that 20 to 30 percent is required. It may be that the 30 and 25 percent amounts in the original work gave data points too close together to do a good extrapolation. In any event, this material was effective in reducing expansion when it was used at its proper amounts of 20 to 30 percent. The work just described was reported by Buck (1985).

27. Work with the reactive granite gneiss (CL-14 G-1(B), CL-14 MS-1) has already been described. Table 41 shows compressive strength data for 3- by 6-in. concrete specimens and 2- by 2- by 2-in. mortar cubes made with this rock and high-alkali cement RC-756(2) through 1 year of testing. The absorption and density of this material as coarse aggregate and fine aggregate are shown below:

	Absorption percent	Relative Density
Rock CL-14 G-1(B)	0.7	2.68
Fine Aggregate CL-14 MS-1	1.0	2.74

The strength data seem normal and do not reflect the slow reactivity of this rock. Length-change data for specimens from the same concrete and mortar mixtures are shown in Table 42 through 30 or 32 months of testing; the testing was at two temperatures (100° and 140° F) like that for gravels described in other work (Buck and Mather 1984). Both the concrete and mortar specimens show expansion of about 0.05 to 0.06 percent after 2 years at the lower temperature; they show definitely significant expansion (~0.10 percent) by this age at the higher temperature. The expansion results for these specimens were much like those for the gravels just mentioned.

28. Length-change data for the mica and the quartz-plagioclase feldspar concentrations that were separated from the granite gneiss and used in three normal size mortar bars are shown in Table 43 through 27 months of testing at two temperatures. The data are generally similar to those for the concrete and for the whole fine aggregate in mortar bars; thus, there is no specific indication here to identify the reactive constituent of the rock.

29. Because of the small amount of the mineral separations, the rest of these separations were used to make small mortar bars. Length-change data for each of the three mineral separations are shown in Table 44 through 1 year of testing at two temperatures. Because of the same lack of material by size fractions, these 18 small bars and the 6 normal size ones shown in the previous table were made using just the No. 30, 50, and 100 sieve size fractions; all of these bars were made to be identical mixtures. Once again, none of these data clearly identifies the reactive component of the rock.

30. In general, the testing of the reactive granite gneiss showed that expansive reaction could be seen in specimens tested at 60° C for more than 1 year and that the quartz was probably the reactive constituent. These findings are parallel to those found by other testing of quartz and quartzite gravels (Buck and Mather 1984).

31. The work involving study of strength development and characterization of reaction products using cement and fly ash or calcium hydroxide (CH) with fly ash or silica fume or the natural pozzolan with water was done to study simplified systems, especially those with CH, to follow the effect of the pozzolan. This included limited and the only use of the eleventh admixture, fly ash AD-570. The work involving the combination of CH and silica fume was summarized by Buck and Burkes (1981). Those data will not be repeated here. They showed good compressive strengths that varied with water content but were not much affected by using one or two parts of fume to CH when the water-to-solids ratio was about 1.0. XRD and SEM studies showed that these

combinations of silica fume and CH with water resulted in the formation of well crystallized calcium silicate hydrate-I (CSH-I) (Taylor 1964). Presumably, this formation of CSH is akin to what happens when the silica fume is added as a pozzolan to inhibit alkali-silica reaction and reacts with CH in the paste. As indicated earlier (Tables 20, 21, and 22), it was an especially effective pozzolan in reducing expansion. Most of this work was done using lime-to-silica (C/S) ratios of about 0.4 to 0.8; a small amount of work was done increasing this ratio to about 1.7 with silica fume and 1.0 and 2.0 for fly ash AD-570, both with CH. The intent was to determine whether CSH-II would form at these higher C/S ratios; it did not.

Conclusions

32. The portion of this project dealing with the ability of different pozzolans, when used at their most effective level with high-alkali cement, to control alkali-silica reaction when the reactive aggregate is at its pessimum (worst) amount was generally successful. Expansions of over 0.1 percent were reduced safely below those levels by this procedure. This is verification of the ability of different pozzolans to control this reaction without the necessity of using low-alkali cement. However, as found by Pepper and Mather (1959), it may and probably will be necessary to use larger amounts of a given pozzolan, up to 60 percent by solid volume replacement of cement.

33. The work with reactive granite gneiss did not specifically identify either mica or feldspar as being the reactive material in this rock. It is believed that strained quartz was the reactive constituent since it was all that was left. Expansion data were generally similar to those obtained in the project devoted to reactivity of quartz (Buck and Mather 1984). These data formed part of the basis for revision of Appendix B of EM 1110-2-2000, Standard Practice for Concrete (US Army Corps of Engineers 1983) to include strained quartz as reactive material.

34. The final portion of all of this work dealt largely with the reaction of silica fume and calcium hydroxide with water; it showed the high reactivity of silica fume and provided data on the well crystallized calcium silicate hydrate Type I that developed by this reaction.

References

Buck, A. D. 1985. "Use of Pozzolan to Control Expansion Due to Alkali-Silica Reaction," pp 501-512, in Technology of Concrete When Pozzolans, Slags, and Chemical Admixtures Are Used, ACI-RILEM Symposium, Monterrey, Mexico.

Buck, A. D., and Burkes, J. P. 1981. "Characterization and Reactivity of Silica Fume," Miscellaneous Paper SL-81-13 (CTIAC Report No. 47), US Army Engineer Waterways Experiment Station, Vicksburg, Miss., also in Proceedings of the Third International Conference on Cement Microscopy, pp 279-285, 16-19 Mar 1981, Houston, Tex.

Buck, A. D., and Mather, K. 1984. "Reactivity of Quartz at Normal Temperatures," Technical Report SL-84-12, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Pepper, L., and Mather, B. 1959. "Effectiveness of Mineral Admixtures in Preventing Excessive Expansion of Concrete Due to Alkali-Aggregate Reaction," American Society for Testing and Materials Proceedings, pp 1178-1203, Vol 59, Philadelphia, Pa.

Reinhold, R. E., Richter, R. E., Buck, A. D., Mather, K., Mather, B., and McDonald, J. E. 1986. "Variations in Cementitious Media," Technical Report SL-86-10, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Taylor, H. F. W., ed. 1964. "The Chemistry of Cements," Vol 1, Chap. 5, and Vol 2, p 372, Academic Press, New York.

US Army Engineer Division Laboratory, Missouri River. 1975. "Petrographic Examination of Quarry Rock for Riprap," Report Series No. 1, Omaha, Nebr.

US Army Corps of Engineers. 1983. "Alkali-Silica Aggregate Reactions," Appendix B, in "Standard Practice for Concrete," Engineer Manual 1110-2-2000, 5 Sep 1985, Washington, DC.

US Army Engineer Waterways Experiment Station. 1949. "Handbook for Concrete and Cement," with quarterly supplements, Vicksburg, Miss.

Table 1

Test Data for RC-688

TO		FROM
A. D. Buck Petrography & X-Ray Br Engr Sci Div Concrete Lab	REPORT OF TESTS OF PORTLAND CEMENT	CORPS OF ENGINEERS U. S. ARMY Cement & Pozzolan Test Br Concrete Laboratory USAE WES

TEST REPORT NO WES-68-74 | BIN NO | QTY REPRESENTED | DATE 15 Apr 74

SPECIFICATION SS-C0192g, Type I, LA | DATE SAMPLED 3 Apr 74

COMPANY United | LOCATION Artesia, Miss. | BRAND

THIS CEMENT DOES X MEET SPECIFICATION REQUIREMENTS

SAMPLE NO	1		1AA		I (AA)			
SiO_2, %	20.9				TiO_2 %	0.29		
Al_2O_3, %	6.2		5.38		Mn_2O_3 %	0.23		
Fe_2O_3, %	2.9		3.02		P_2O_5	0.19	(Colorimetric)	
MgO, %	0.9							
SO_3, %	2.6							
LOSS ON IGNITION, %	0.6							
ALKALIES-TOTAL AS Na_2O, %	0.44	Water Soluble Alkali As Na_2O %						0.16
Na_2O, %	0.17							0.03
K_2O, %	0.41							0.20
INSOLUBLE RESIDUE, %	0.13							
CaO, %	65.5							
C_3S, %	54.6							
C_3A, %	11.5		9.7					
C_2S, %	18.3							
$C_3A + C_3S$, %	66							
C_4AF, %	8.76							
$C_4AF + 2C_3A$, %								
HEAT OF HYDRATION 7D, CAL/G	85							
HEAT OF HYDRATION 28D, CAL/G	96							
SURFACE AREA, SQ CM/G (A.P.)	3320							
AIR CONTENT, %	9.5							
COMP STRENGTH 3 D, PSI	2860	COMP STR, 90 D, PSI			5860			
COMP STRENGTH 7 D, PSI	4040	COMP STR, 180 D, PSI			6060			
COMP STRENGTH 28 D, PSI	5320	COMP STR, 365 D, PSI						
FALSE SET-PEN FINAL, %								
SAMPLE NO	1							
AUTOCLAVE EXP, %	0.06							
INITIAL SET, HR MIN	3:10							
FINAL SET, HR MIN	5:05							
SAMPLE NO								
AUTOCLAVE EXP, %								
INITIAL SET, HR MIN								
FINAL SET, HR MIN								

REMARKS

Job No. 441-C145.14C111

CF:
Mr. Tynes

W. G. MILLER
Chemist
Chief, Cement and Pozzolan Test Branch

Table 2

Test Data for RC-688(2)

Mrs K. Mather Ch, Engr Sci Div CL	REPORT OF TESTS OF PORTLAND CEMENT RC-688(2)	FROM: CORPS OF ENGINEERS U. S. ARMY Cem & Pozz Test Br Engr Sci Div CL

TEST REPORT NO. | BIN NO. | CWT REPRESENTED: 1 Sample | DATE 11 Feb 77

SPECIFICATION: | DATE SAMPLED:

COMPANY: | LOCATION | BRAND:

THIS CEMENT DOES MEET SPECIFICATION REQUIREMENTS

SAMPLE NO.	RC-688(2)			AA	AA			
SiO_2, %	20.0				TiO_2	0.44		
Al_2O_3, %	6.0			5.40	Mn_2O_3	0.03		
Fe_2O_3, %	2.8			2.78	P_2O_5	0.33		
MgO, %	1.1							
SO_3, %	2.6							
LOSS ON IGNITION, %	1.3							
ALKALIES-TOTAL AS Na_2O, %	0.37							
Na_2O, %	0.19							
K_2O, %	0.27							
INSOLUBLE RESIDUE, %	0.09							
CaO, %	65.8							
C_3S, %	64.4							
C_3A, %	11.1			9.6				
C_2S, %	8.9							
$C_3A + C_3S$, %	75.5							
C_4AF, %	8.4							
$C_4AF + 2C_3A$, %	30.6							
HEAT OF HYDRATION, 7D, CAL/G								
HEAT OF HYDRATION, 28D, CAL/G								
SURFACE AREA, SQ CM/G (A.P.)	3420							
AIR CONTENT, %	9.1							
COMP. STRENGTH, 3 D, PSI	2830							
COMP. STRENGTH, 7 D, PSI	4380							
COMP. STRENGTH, D, PSI								
FALSE SET-PEN. F/I, %								
SAMPLE NO.	RC-688(2)							
AUTOCLAVE EXP., %	0.08							
INITIAL SET, HR/MIN	2:35							
FINAL SET, HR/MIN	4:40							
SAMPLE NO.								
AUTOCLAVE EXP., %								
INITIAL SET, HR/MIN								
FINAL SET, HR/MIN								

REMARKS: Memorandum for Record No. 1985; Job No. 545-C530.17C141

W. G. MILLER
Chemist
Chief, Cement and Pozzolan Test Branch

ENG FORM 1 MAR 72 6008-R

Table 3

Test Data for RC-720

TO:	REPORT OF TESTS OF PORTLAND CEMENT	FROM: CORPS OF ENGINEERS U. S. ARMY
Mrs. K .ather Ch, X-Ray & Petro Engr Sciences Div CL		Cem & Pozz Test Br Engr Sciences Div CL

TEST REPORT NO WES-31-75 | BIN NO. | CMT REPRESENTED | DATE 10 Mar 75

SPECIFICATION: Type I | DATE SAMPLED

COMPANY: Dundee | LOCATION Dundee, Mich. | BRAND:

THIS CEMENT DOES MEET SPECIFICATION REQUIREMENTS

SAMPLE NO.								
SiO_2, %	21.1							
Al_2O_3, %	5.7							
Fe_2O_3, %	2.8							
MgO, %	3.7							
SO_3, %	2.6							
LOSS ON IGNITION, %	1.1	Water Soluble Alkalies						
ALKALIES-TOTAL AS Na_2O, %	0.79		0.25					
Na_2O, %	0.32		- 0.05					
K_2O, %	0.72		0.31					
INSOLUBLE RESIDUE, %	0.18							
CaO, %	62.6							
C_3S, %	45.4							
C_3A, %	10.3							
C_2S, %	26.2							
$C_3A + C_3S$, %	55.8							
C_4AF, %	8.4							
$C_4AF + 2C_3A$, %	29.0							
HEAT OF HYDRATION, 7D, CAL/G								
HEAT OF HYDRATION, 28D, CAL/G								
SURFACE AREA, SQ CM/G (A P)	3350							
AIR CONTENT, %	9.2							
COMP. STRENGTH, 3D, PSI	2980							
COMP. STRENGTH, 7D, PSI	4120							
COMP. STRENGTH, 28D, PSI	5130							
FALSE SET-PEN. F/I, %								
SAMPLE NO.								
AUTOCLAVE EXP., %	0.18							
INITIAL SET, HR/MIN Vicat	2:00							
FINAL SET, HR/MIN Vicat	4:10							
SAMPLE NO.								
AUTOCLAVE EXP., %								
INITIAL SET, HR/MIN								
FINAL SET, HR/MIN								

REMARKS:

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W. G. Miller

W. G. MILLER
Chemist
Chief, Cement and Pozzolan Test Branch

ENG FORM 6003-R

Table 4

Test Data for RC-725

TO:	REPORT OF TESTS OF PORTLAND CEMENT RC-725	FROM: CORPS OF ENGINEERS U. S. ARMY Structures Laboratory USAE Waterways Exp St ATTN: Cem & Pozz Group P.O. Box 631 Vicksburg, MS 39180

TEST REPORT NO.	BIN NO	CWT REPRESENTED:	DATE:
SPECIFICATION: Type I		DATE SAMPLED:	
COMPANY: Missouri Portland	LOCATION Joppa, IL		BRAND:
THIS CEMENT DOES MEET SPECIFICATION REQUIREMENTS			

SAMPLE NO. (Analysis)	1(WET)	1(AA)		1(AA)				
SiO_2, %	20.6			TiO_2%	0.23			
Al_2O_3, %	4.6	4.3		Mn_2O_3%	0.03			
Fe_2O_3, %	2.9	3.0		P_2O_5%	0.04	(Colormetric)		
MgO, %	3.6							
SO_3, %	2.6							
LOSS ON IGNITION, %	1.3							
ALKALIES-TOTAL AS Na_2O, %	0.78	Water	Soluble	Alkali	as Na_2O%		0.59	
Na_2O, %	0.12						0.06	
K_2O, %	1.00						0.80	
INSOLUBLE RESIDUE, %	0.13							
CaO, %	63.7							
C_3S, %	61							
C_3A, %	7	6.3						
C_2S, %	13							
$C_3A + C_3S$, %	68							
C_4AF, %	9							
$C_4AF + 2 C_3A$, %								
HEAT OF HYDRATION 7D, CAL/G								
HEAT OF HYDRATION 28D, CAL/G								
SURFACE AREA, SQ CM/G (A.P.)	3540							
AIR CONTENT, %	9.5							
COMP STRENGTH, 3 D, PSI	3010	COMP STR.	90	D. PSI	5320			
COMP STRENGTH, 7 D, PSI	3880	COMP STR.	180	D. PSI	5610			
COMP STRENGTH 28 D PSI	4800	COMP STR.	365	D. PSI	5560			
FALSE SET-PEN F/I, %								
SAMPLE NO.	1							
AUTOCLAVE EXP., %	0.09							
INITIAL SET, HR/MIN	3:10							
FINAL SET, HR/MIN	5:10							
SAMPLE NO.								
AUTOCLAVE EXP., %								
INITIAL SET, HR/MIN								
FINAL SET, HR/MIN								

REMARKS:

W. G. MILLER
Chemist
Chief, Cement & Pozzolan Group

ENG FORM 1 MAR 70 4008-R

Table 5

Test Data for RC-756

TO		FROM CORPS OF ENGINEERS U.S. ARMY
Mrs. K. Mather Ch, X-Ray & Petro Engr Sciences Div CL	REPORT OF TESTS OF PORTLAND CEMENT	Cem & Pozz Test Br Engr Sciences Div CL

TEST REPORT NO WES-5-76	BRAND	AMOUNT REPRESENTED 1 Sample	DATE 19 Jan 76
SPECIFICATION Type I, High Alkali		DATE SAMPLED	
COMPANY Harry T. Campbell	LOCATION Baltimore, MD	PLANT	
THIS CEMENT DOES X MEET SPECIFICATION REQUIREMENTS			

SAMPLE NO (Analysis)	1(WET)	1(AA)	1(AA)		
SiO_2 %	19.9		TiO_2	0.24	
Al_2O_3 %	6.9	6.4	Mn_2O_3	0.06	
Fe_2O_3 %	2.2	2.1	P_2O_5	0.30	(Colormetric)
MgO %	3.0				
SO_3 %	2.9				
LOSS ON IGNITION %	0.7				
ALKALIES-TOTAL AS Na_2O %	1.16	Water Soluble Alkali as Na_2O			0.86
Na_2O %	0.32				0.15
K_2O %	1.27				1.08
INSOLUBLE RESIDUE %	0.30				
CaO %	62.9				
C_3S %	48				
C_3A %	15	13			
C_2S %	21				
$C_3A + C_3S$ %	62				
C_4AF %	7				
$C_4AF + 2C_3A$ %					
HEAT OF HYDRATION 7D CAL/G					
HEAT OF HYDRATION 28D CAL/G					
SURFACE AREA SQ CM/G (AIR PERM)	4030				
AIR CONTENT %	8.8				
COMP STRENGTH 3 D PSI	3510	COMP STR, 90 D, PSI 4920			
COMP STRENGTH 7 D PSI	4050	COMP STR, 180 D, PSI 5290			
COMP STRENGTH 28 D PSI	4690	COMP STR, 365 D, PSI 5400			
FALSE SET-PEN FINAL %					
SAMPLE NO	1				
AUTOCLAVE EXP %	0.10				
INITIAL SET HR MIN	2:45				
FINAL SET HR MIN	5:15				
SAMPLE NO					
AUTOCLAVE EXP %					
INITIAL SET HR MIN					
FINAL SET HR MIN					

REMARKS Sample received from Mrs. Mather, Job No. 545-0526.1601...

W. G. MILLER
Chemist
Chief, Cement and Pozzolan Test Branch

Table 6

Test Data for RC-756(2)

TO:	REPORT OF TESTS OF PORTLAND CEMENT RC-756 (2)	FROM: CORPS OF ENGINEERS U. S. ARMY Structures Laboratory USAE Waterways Exp Station ATTN: Cem & Pozz Group P.O. Box 631 Vicksburg, MS 39180

TEST REPORT NO. KM510(30)78	BIN NO.	CWT REPRESENTED:	DATE: DEC 78
SPECIFICATION: Type I		DATE SAMPLED:	
COMPANY: Harry T. Campbell	LOCATION Towson, MD		BRAND:
THIS CEMENT DOES MEET SPECIFICATION REQUIREMENTS			

SAMPLE NO. (Analysis)	1(WET)	1(AA)		1(AA)				
SiO_2, %	19.9			TiO_2%	0.24			
Al_2O_3, %	6.2	5.7		Mn_2O_3	0.05			
Fe_2O_3, %	2.1	2.1		P_2O_5	0.27	(Colormetric)		
MgO, %	2.7							
SO_3, %	3.0							
LOSS ON IGNITION, %	1.0							
ALKALIES-TOTAL AS Na_2O, %	1.31							
Na_2O, %	0.28							
K_2O, %	1.57							
INSOLUBLE RESIDUE, %	0.17							
CaO, %	62.9							
C_3S, %	52							
C_3A, %	13	12						
C_2S, %	18							
$C_3A + C_3S$, %	65							
C_4AF, %	6							
$C_4AF + 2C_3A$, %								
HEAT OF HYDRATION, 7D, CAL/G								
HEAT OF HYDRATION, 28D, CAL/G								
SURFACE AREA, SQ CM/G (A.P.)	3770							
AIR CONTENT, %	8.8							
COMP. STRENGTH, 3 D, PSI	3700							
COMP. STRENGTH, 7 D, PSI	4480							
COMP. STRENGTH, 28 D, PSI	5130							
FALSE SET-PEN. F/I, %								
SAMPLE NO.	1							
AUTOCLAVE EXP., %	0.09							
INITIAL SET, HR/MIN	2:35							
FINAL SET, HR/MIN	4:55							
SAMPLE NO.								
AUTOCLAVE EXP., %								
INITIAL SET, HR/MIN								
FINAL SET, HR/MIN								

REMARKS:

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W. G. MILLER
Chemist
Chief, Cement & Pozzolan Test Branch

ENG FORM 1 MAR 72 6008-R

Table 7

Test Data for RC-761

TO:	REPORT OF TESTS OF PORTLAND CEMENT	FROM: CORPS OF ENGINEERS U. S. ARMY
Mrs. K. Mather Ch, X-Ray & Petro Engr Sciences Div CL	RC-761	Cem & Pozz Test Br Engr Sciences Div CL

TEST REPORT NO. WES-42-76	BIN NO.	CMT REPRESENTED: Sample	DATE: 25 Feb 76
SPECIFICATION: Type I		DATE SAMPLED: 13 Feb 76	
COMPANY: Harry T. Campbell	LOCATION: Baltimore, MD		BRAND:
THIS CEMENT DOES MEET SPECIFICATION REQUIREMENTS			

SAMPLE NO. (Analysis)	1 (WET)	1 (AA)		1 (AA)				
SiO_2, %	19.9			TiO_2 %	0.24			
Al_2O_3, %	6.6	6.0		Mn_2O_3	0.06			
Fe_2O_3, %	2.1	2.0		P_2O_5	0.25	(Colormetric)		
MgO, %	2.8							
SO_3, %	2.9							
LOSS ON IGNITION, %	0.9							
ALKALIES-TOTAL AS Na_2O, %	1.07	Water Soluble Alkali as Na_2O%					0.86	
Na_2O, %	0.27						0.15	
K_2O, %	1.22						1.08	
INSOLUBLE RESIDUE, %	0.10							
CaO, %	62.9							
C_3S, %	47							
C_3A, %	14	13						
C_2S, %	19							
$C_3A + C_3S$, %	64							
C_4AF, %	6							
$C_4AF + 2C_3A$, %	36							
HEAT OF HYDRATION, 7D, CAL/G								
HEAT OF HYDRATION, 28D, CAL/G								
SURFACE AREA, SQ CM/G (A.P.)	3970							
AIR CONTENT, %	8.0							
COMP. STRENGTH, 3 D, PSI	3790							
COMP. STRENGTH, 7 D, PSI	4420							
COMP. STRENGTH, D, PSI								
FALSE SET-PEN. F/I, %								
SAMPLE NO.	I							
AUTOCLAVE EXP., %	0.10							
INITIAL SET, HR/MIN	3:00							
FINAL SET, HR/MIN	5:45							
SAMPLE NO.								
AUTOCLAVE EXP., %								
INITIAL SET, HR/MIN								
FINAL SET, HR/MIN								

REMARKS: Sample received from Mrs. Mather, Job No. 545-C526.16C141.

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W. G. Miller

W. G. MILLER
Chemist
Chief, Cement and Pozzolan Test Branch

ENG FORM 6000-R

Table 8

Test Data for AD-505

Structures Laboratory USAE Waterways Exp St ATTN: Cem & Pozz Test Br P. O. Box 631 Vicksburg, MS 39180	REPORT OF TESTS ON POZZOLAN	Report No: KM510(49)78 Admixture No: AD 505 Date: DEC 78

POZZOLAN CLASS: F	DESCRIPTION: Subbituminous Fly Ash	
COMPANY: Kansas City P & L Co	LOCATION: Hawthorne Plant, Kansas City, MO	
MEMO NO: 1955	DATE: 10/6/75	JOB NO: 545-C-530
MEMO SUBJECT: Variations in Cementitious Media		

CHEMICAL COMPOSITION

SiO_2 %	45.88	Moisture Content %	0.14	Cr_2O_3 %	
Al_2O_3 %	21.44	LOI, % (750 C)	3.81	Chloride %	
Fe_2O_3 %	10.88	LOI, % (1000 C)			
MgO %	2.50	TiO_2 %			
SO_3 %	1.11	P_2O_5 %			
CaO %	11.11	Mn_2O_3 %			

Alkalies %	Water Soluble	Available (C-618)	Acid Soluble	Total Alkali
Na_2O %	0.01	0.12	0.04	0.37
K_2O %	0.01	0.60	0.20	1.93
Total as Na_2O%	0.02	0.51	0.17	1.64

PHYSICAL TESTS

Specific Gravity: 2.44	Fineness % retained on 325 Sieve
Surface Area: 9130 sqcm/cc, porosity	e = 0.416

Tests with portland cement cured @ 73.4 ± 3 F

Portland Cement Co:	United			Citadel		
Location:	Artesia, MS			Birmingham, AL		
Research Cement No & Type:	RC-688 I, LA			RC-705. II, LA, HH		
Autoclave Expansion, 20% Replacement, %	0.01			0.07		
% Replace of Cement by Volume	0	30	60	0	30	60
Heat of Hydration, 7 days, Cal/gm	84.8	70.2	49	67.7	56.4	46.8
Heat of Hydration, 28 days, Cal/gm	96.5	83.2	62	78.8	65.4	56.5
Compressive Strength, 3 days psi	2880	2320	690	1700	1450	730
Compressive Strength, 7 days psi	4080	3010	930	2510	1880	920
Compressive Strength, 28 days psi	5320	4530	1290	4040	2910	1380
Compressive Strength, 90 days psi	5860	6060	4200	5760	5320	2600
Compressive Strength, 180 days psi	6050	6760	4770	5990	6610	4010
Compressive Strength, 365 days psi	6300	6760	5860	6070	6060	4840
Water - Cement Ratio	0.485	0.485	0.485	0.485	0.485	0.485
Flow	111	108	110	122	111	103

Pozzolanic Activity Index, ASTM C618
With Lime @ 7 days PSI 1790
With Portland Cement (RC-688) at 28 days percent of Control 113

Test for Pozzolan Hydraulic Activity

Compressive Strength (PSI)

W/C	3days	7days	28days
0.417	55	70	160

W. G. MILLER
Chemist
Chief, Cement & Pozzolan Test Branch

Table 9

Test Data for AD-506

Structures Laboratory USAE Waterways Exp St ATTN: Cem & Pozz Test Br P. O. Box 631 Vicksburg, MS 39180	REPORT OF TESTS ON POZZOLAN	Report No: Admixture No: AD 506 Date:

POZZOLAN CLASS: F	DESCRIPTION: Lignite Fly Ash	
COMPANY: Trinity (Gen Port)	LOCATION: Big Brown Plant, Fairfield, TX	
MEMO NO: 1985	DATE: 10/6/75	JOB NO: 545-C-530
MEMO SUBJECT: Variations in Cementitious Media		

CHEMICAL COMPOSITION

SiO_2 %	50.4	Moisture Content %	0.17	Cr_2O_3 %	
Al_2O_3 %	18.41	LOI, % (750°C)	0.85	Chloride %	
Fe_2O_3 %	4.16	LOI, % (1000°C)			
MgO %	3.54	TiO_2 %			
SO_3 %	1.30	P_2O_5 %			
CaO %	19.77	Mn_2O_3 %			

Alkalies	Water Soluble	Available (C-618)	Acid Soluble	Total Alkali
Na_2O %	0.00	0.21	0.20	0.57
K_2O %	0.00	0.18	0.12	0.53
Total as Na_2O %	0.00	0.33	0.28	0.92

PHYSICAL TESTS

Specific Gravity: 2.56	Fineness: % retained on 325 Sieve
Surface Area: 6780 sqcm/cc, porosity	e= 0.390

Tests with portland cement cured @ 73.4 ± 3° F

Portland Cement Co.:	United			Citadel		
Location:	Artesia, MS			Birmingham, AL		
Research Cement No & Type:	RC-688, I,			RC-705, II, LA, HH		
Autoclave Expansion, 20% Replacement, %	0.04			0.09		
% Replace of Cement by Volume	0	30	60	0	30	60
Heat of Hydration, 7 days, Cal/gm	84.8	72.9	53	67.7	55.6	45
Heat of Hydration, 28 days, Cal/gm	96.5	85.4	67	78.8	70.3	57
Compressive Strength, 3 days psi	2880	2260	1010	1700	1320	780
Compressive Strength, 7 days psi	4080	3050	1590	2510	1730	1070
Compressive Strength, 28 days psi	5320	4200	2460	4040	2910	2180
Compressive Strength, 90 days psi	5860	5020	4160	5760	4920	3930
Compressive Strength, 180 days psi	6050	5430	4920	5990	5820	5470
Compressive Strength, 1 year psi		6100	5450		6380	5330
Water - Cement Ratio	0.485	0.485	0.485	0.485	0.485	0.48
Flow %	111	111	110	122	118	106

Pozzolanic Activity Index, ASTM C618
With Lime @ 7 days PSI 1030
With Portland Cement (RC-688) at 28 days percent of Control 88

Test for Pozzolan Hydraulic Activity

Compressive Strength (PSI)

W/C	3days	7days	28days
0.433	30	fell apart	test discontinued

W. G. MILLER
Chemist
Chief, Cement & Pozzolan Test Branch

Table 10

Test Data for AD-507

Structures Laboratory USAE Waterways Exp St ATTN: Cem & Pozz Test Br P. O. Box 631 Vicksburg, MS 39180	REPORT OF TESTS ON POZZOLAN	Report No: Admixture No: AD 507 Date:

POZZOLAN CLASS: F	DESCRIPTION: Subbituminous Fly Ash
COMPANY: Union Electric Co.	LOCATION: St. Louis, MO
MEMO NO: 1985	DATE: 10/6/75 JOB NO: 545-C-530
MEMO SUBJECT: Variations in Cementitious Media	

CHEMICAL COMPOSITION

SiO_2 %	44.87	Moisture Content %	0.28	Cr_2O_3 %	
Al_2O_3 %	21.83	LOI, % (750°C)	5.69	Chloride %	
Fe_2O_3 %	17.20	LOI, % (1000°C)			
MgO %	0.67	TiO_2 %			
SO_3 %	1.12	P_2O_5 %			
CaO %	4.77	Mn_2O_3 %			

Alkalies	Water Soluble	Available (C-618)	Acid Soluble	Total Alkali
Na_2O %	0.14	0.50	0.34	1.38
K_2O %	0.03	0.78	0.30	2.18
Total as Na_2O %	0.16	1.01	0.54	2.81

PHYSICAL TESTS

Specific Gravity: 2.37 | Fineness: % retained on 325 Sieve

Surface Area: 7660 sqcm/cc, porosity e= 0.480

Tests with portland cement cured @ 73.4 ± 3° F

Portland Cement Co.:	United			Citadel		
Location:	Artesia, MS			Birmingham, AL		
Research Cement No & Type:	RC-688, I, LA			RC-705, II, LA, HH		
Autoclave Expansion, 20% Replacement, %	0.01			0.05		
% Replace of Cement by Volume	0	30	60	0	30	60
Heat of Hydration, 7 days, Cal/gm	84.8	70.5	48.2	67.7	.57	41
Heat of Hydration, 28 days, Cal/gm	96.5	83.4	64.5	78.8	.66	48
Compressive Strength, 3 days psi	2880	1910	830	1700	1320	690
Compressive Strength, 7 days psi	4080	2600	1110	2510	1660	830
Compressive Strength, 28 days psi	5320	3700	1720	4040	2640	1560
Compressive Strength, 90 days psi	5860	5320	3040	5760	4720	3590
Compressive Strength, 180 days psi	6050	5820	3460	5990	5460	4240
Compressive Strength, 1 year psi		6460	4520		6090	4820
Water - Cement Ratio	0.485	0.485	0.485	0.485	0.485	0.485
Flow %	111	65	62	122	78	60

Pozzolanic Activity Index, ASTM C618
With Lime @ 7 days PSI 1080
With Portland Cement (RC-688) at 28 days percent of Control 80

Test for Pozzolan Hydraulic Activity

Compressive Strength (PSI)

W/C	3days	7days	28days
0.583	to soft to test		

W. G. MILLER
Chemist
Chief, Cement & Pozzolan Test Branch

Table 11

Test Data for AD-509

Structures Laboratory USAE Waterways Exp St ATTN: Cem & Pozz Test Br P. O. Box 631 Vicksburg, MS 39180	REPORT OF TESTS ON POZZOLAN	Report No: Admixture No: AD 509 Date:

POZZOLAN CLASS: F		DESCRIPTION: Lignite Fly Ash	
COMPANY: Basin Elec. PWR		LOCATION: Stanton, N.D.	
MEMO NO: 1985	DATE: 10/6/75	JOB NO: 545-C-530	
MEMO SUBJECT: Variations in Cementitious Media			

CHEMICAL COMPOSITION

SiO_2 %	49.7	Moisture Content %	0.14	Cr_2O_3 %	
Al_2O_3 %	17.78	LOI, % (750°C)	0.20	Chloride %	
Fe_2O_3 %	6.29	LOI, % (1000°C)			
MgO %	4.86	TiO_2 %			
SO_3 %	1.09	P_2O_5 %			
CaO %	13.1	Mn_2O_3 %			

Alkalies	Water Soluble	Available (C-618)	Acid Soluble	Total Alkali
Na_2O %	0.38	1.38	1.31	4.00
K_2O %	0.01	0.38	0.57	1.76
Total as Na_2O %	0.39	1.63	1.69	5.16

PHYSICAL TESTS

Specific Gravity: 2.39 | Fineness: % retained on 325 Sieve

Surface Area: 4690 sqcm/cc, porosity e= 0.387

Tests with portland cement cured @ 73.4 ± 3° F

Portland Cement Co.:	United			Citadel		
Location:	Artesia, MS			Birmingham, AL		
Research Cement No & Type:	RC-688, I, LA			RC-705, II, LA, HH		
Autoclave Expansion, 20% Replacement, %	0.03			0.09		
% Replace of Cement by Volume	0	30	60	0	30	60
Heat of Hydration, 7 days, Cal/gm	84.8	72	51	67.7	52	49
Heat of Hydration, 28 days, Cal/gm	96.5	82	66	78.8	62	56
Compressive Strength, 3 days psi	2880	1880	920	1700	1150	640
Compressive Strength, 7 days psi	4080	2530	1200	2510	1540	820
Compressive Strength, 28 days psi	5320	3620	1810	4040	2640	1520
Compressive Strength, 90 days psi	5860	4460	3090	5760	4140	2750
Compressive Strength, 180 days psi	6050	5000	3470	5990	4750	3200
Compressive Strength, 1 year psi		5320	3980		5310	3520
Water - Cement Ratio	0.485	0.485	0.485	0.485	0.485	0.485
Flow %	111	93	74	122	105	79

Pozzolanic Activity Index, ASTM C618
With Lime @ 7 days PSI 1160
With Portland Cement (RC-688) at 28 days percent of Control 76

Test for Pozzolan Hydraulic Activity

Compressive Strength (PSI)

W/C	3days	7days	28days
0.477	to soft to test		

W. G. MILLER
Chemist
Chief, Cement & Pozzolan Test Branch

Table 12

Test Data for AD-510

Structures Laboratory USAE Waterways Exp St ATTN: Cem & Pozz Test Br P. O. Box 631 Vicksburg, MS 39180	REPORT OF TESTS ON POZZOLAN	Report No: Admixture No: AD 510 Date:

POZZOLAN CLASS: C	DESCRIPTION: Lignite Fly Ash
COMPANY: Ottertail Power	LOCATION: Fergus Falls, MN
MEMO NO: 1985 DATE: 10/6/75	JOB NO: 545-C-530
MEMO SUBJECT: Variations in Cementitious Media	

CHEMICAL COMPOSITION

SiO_2 %	23.48	Moisture Content %	0.29	Cr_2O_3 %	
Al_2O_3 %	16.36	LOI, % (750°C)	1.14	Chloride %	
Fe_2O_3 %	9.08	LOI, % (1000°C)			
MgO %	8.43	TiO_2 %			
SO_3 %	5.31	P_2O_5 %			
CaO %	29.94	Mn_2O_3 %			

Alkalies	Water Soluble	Available (C-618)	Acid Soluble	Total Alkali
Na_2O %	0.63	2.40	2.51	3.28
K_2O %	0.05	0.23	0.25	0.39
Total as Na_2O %	0.66	2.55	2.67	3.54

PHYSICAL TESTS

Specific Gravity: 2.75 | Fineness: % retained on 325 Sieve

Surface Area: 8750 sqcm/cc, porosity e= 0.460

Tests with portland cement cured @ 73.4 ± 3° F

Portland Cement Co.:	United			Citadel		
Location:	Artesia, MS			Birmingham, AL		
Research Cement No & Type:	RC-688, I, LA			RC-705, II, LA, HH		
Autoclave Expansion, 20% Replacement, %	0.12			0.32		
% Replace of Cement by Volume	0	30	60	0	30	60
Heat of Hydration, 7 days, Cal/gm	84.8	82	73	67.7	67	69
Heat of Hydration, 28 days, Cal/gm	96.5	90	81	78.8	76	77
Compressive Strength, 3 days psi	2890	2710	2380	1700	1990	1440
Compressive Strength, 7 days psi	4080	3650	3030	2510	2530	1800
Compressive Strength, 28 days psi	5320	4920	4090	4040	3730	2950
Compressive Strength, 90 days psi	5860	5460	4970	5760	5270	4600
Compressive Strength, 180 days psi	6050	6260	5250	5990	5320	5120
Compressive Strength, 1 year psi		5840	5740		5610	5220
Water - Cement Ratio	0.485	0.435	0.485	0.485	0.435	0.48
Flow %	111	114	73	122	111	10

Pozzolanic Activity Index, ASTM C618
With Lime @ 7 days PSI 1500
With Portland Cement (RC-688) at 28 days percent of Control 85

Test for Pozzolan Hydraulic Activity

Compressive Strength (PSI)

W/C	3days	7days	28days
0.450	1340	1950	2860

W. G. MILLER
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Chief, Cement & Pozzolan Test Branch

Table 13

Test Data for AD-511

Structures Laboratory USAE Waterways Exp St ATTN: Cem & Pozz Test Br P. O. Box 631 Vicksburg, MS 39180	REPORT OF TESTS ON POZZOLAN	Report No: Admixture No: AD 511 Date:

POZZOLAN CLASS: F	DESCRIPTION: Bituminous Fly Ash	
COMPANY: Amax	LOCATION: Stilesboro, GA (Plant Bowen)	
MEMO NO: 1985	DATE: 10/6/75	JOB NO: 545-C-530
MEMO SUBJECT: Variations in Cementitious Media		

CHEMICAL COMPOSITION

SiO_2 %	45.4	Moisture Content %	0.31	Cr_2O_3 %	
Al_2O_3 %	24.34	LOI, % (750°C)	4.26	Chloride %	
Fe_2O_3 %	15.02	LOI, % (1000°C)			
MgO %	1.12	TiO_2 %			
SO_3 %	0.73	P_2O_5 %			
CaO %	2.69	Mn_2O_3 %			

Alkalies	Water Soluble	Available (C-618)	Acid Soluble	Total Alkali
Na_2O %	0.02	0.14	0.06	0.38
K_2O %	0.03	0.88	0.36	2.61
Total as Na_2O %	0.04	0.72	0.30	2.10

PHYSICAL TESTS

Specific Gravity: 2.45	Fineness: % retained on 325 Sieve
Surface Area: 6870	sqcm/cc, porosity e= 0.463

Tests with portland cement cured @ 73.4 ± 3° F

Portland Cement Co.:	United			Citadel		
Location:	Artesia, MS			Birmingham, AL		
Research Cement No & Type:	RC-688, I, LA			RC-705, II, LA, HH		
Autoclave Expansion, 20% Replacement, %	0.00			0.04		
% Replace of Cement by Volume	0	30	60	0	30	60
Heat of Hydration, 7 days, Cal/gm	84.8	63	47	67.7	55	39
Heat of Hydration, 28 days, Cal/gm	96.5	83	62	78.8	68	45
Compressive Strength, 3 days psi	2880	1900	880	1700	1200	620
Compressive Strength, 7 days psi	4080	2650	1180	2510	1560	760
Compressive Strength, 28 days psi	5320	3830	1790	4040	2600	1420
Compressive Strength, 90 days psi	5860	5390	3040	5760	4850	2740
Compressive Strength, 180 days psi	6050	5870	3750	5990	5480	3670
Compressive Strength, 1 year psi		5140	4870		6400	4260
Water - Cement Ratio	0.485	0.485	0.485	0.485	0.485	0.48
Flow %	111	90	74	122	96	79

Pozzolanic Activity Index, ASTM C618
With Lime @ 7 days PSI 1020
With Portland Cement (RC-688) at 28 days percent of Control 91

W. G. MILLER
Chemist
Chief, Cement & Pozzolan Test Branch

Table 14

Test Data for AD-512

Structures Laboratory USAE Waterways Exp St ATTN: Cem & Pozz Test Br P. O. Box 631 Vicksburg, MS 39180	REPORT OF TESTS ON POZZOLAN	Report No: Admixture No: AD 512 Date:

POZZOLAN CLASS: F		DESCRIPTION: Subbituminous Fly Ash	
COMPANY: Iowa Public Service		LOCATION: Sioux City, IA	
MEMO NO: 1985	DATE: 10/6/75	JOB NO: 545-C-530	
MEMO SUBJECT: Variations in Cementitious Media			

CHEMICAL COMPOSITION

SiO_2 %	43.28	Moisture Content %	0.21	Cr_2O_3 %	
Al_2O_3 %	19.71	LOI, % (750°C)	1.14	Chloride %	
Fe_2O_3 %	7.68	LOI, % (1000°C)			
MgO %	3.34	TiO_2 %			
SO_3 %	1.75	P_2O_5 %			
CaO %	20.32	Mn_2O_3 %			

Alkalies	Water Soluble	Available (C-618)	Acid Soluble	Total Alkali
Na_2O %	0.00	0.23	0.13	0.45
K_2O %	0.00	0.77	0.29	1.54
Total as Na_2O %	0.00	0.74	0.32	1.46

PHYSICAL TESTS

Specific Gravity: 2.58 | Fineness: % retained on 325 Sieve

Surface Area: 12830 sqcm/cc, porosity e= 0.458

Tests with portland cement cured @ 73.4 ± 3° F

	United			Citadel		
Portland Cement Co.:	United			Citadel		
Location:	Artesia, MS			Birmingham, AL		
Research Cement No & Type:	RC-688, I, LA			RC-705, II, LA, HH		
Autoclave Expansion, 20% Replacement, %	0.08			0.14		
% Replace of Cement by Volume	0	30	60	0	30	60
Heat of Hydration, 7 days, Cal/gm	84.8	74	[illegible]	67.7	63	43
Heat of Hydration, 28 days, Cal/gm	96.5	86	73	78.8	72	63
Compressive Strength, 3 days psi	2880	2330	1130	1700	1430	760
Compressive Strength, 7 days psi	4080	3190	1630	2510	2040	1170
Compressive Strength, 28 days psi	5320	4760	2560	4040	3680	1840
Compressive Strength, 90 days psi	5860	6360	5030	5760	6000	4040
Compressive Strength, 180 days psi	6050	7450	5220	5990	7395	5950
Compressive Strength, 1 year psi		7810	7000		6900	
Water - Cement Ratio	0.485	0.465	0.485	0.485	0.461	0.485
Flow %	111	114	138	122	120	139

Pozzolanic Activity Index, ASTM C618

With Lime @ 7 days PSI 1750

With Portland Cement (RC-688) at 28 days percent of Control 111

Test for Pozzolan Hydraulic Activity

Compressive Strength (PSI)

W/C	3days	7days	28days
0.400	75	20	fell apart

W. C. MILLER
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Chief, Cement & Pozzolan Test Branch

Table 15

Test Data for AD-513

Structures Laboratory USAE Waterways Exp St ATTN: Cem & Pozz Test Br P. O. Box 631 Vicksburg, MS 39180	REPORT OF TESTS ON POZZOLAN	Report No: Admixture No: AD 513 Date:

POZZOLAN CLASS: C	DESCRIPTION: Lignite Fly Ash		
COMPANY: Colorado Public Serv	LOCATION: Pueblo, CO. (Comanche Plant)		
MEMO NO: 1955	DATE: 10/6/75	JOB NO: 545-C-530	
MEMO SUBJECT: Variations in Cementitious Media			

CHEMICAL COMPOSITION

SiO_2 %	38.12	Moisture Content %	0.14	Cr_2O_3 %	
Al_2O_3 %	25.68	LOI, % (750°C)	0.14	Chloride %	
Fe_2O_3 %	4.65	LOI, % (1000°C)			
MgO %	4.42	TiO_2 %			
SO_3 %	1.55	P_2O_5 %			
CaO %	21.01	Mn_2O_3 %			

Alkalies	Water Soluble	Available (C-613)	Acid Soluble	Total Alkali
Na_2O %	0.01	0.47	0.67	1.30
K_2O %	0.00	0.28	0.28	0.58
Total as Na_2O %	0.01	0.65	0.85	1.65

PHYSICAL TESTS

Specific Gravity: 2.61 | Fineness: % retained on 325 Sieve

Surface Area: 12,790 sqcm/cc, porosity e= 0.475

Tests with portland cement cured @ 73.4 ± 3° F

Portland Cement Co.:	United			Citadel		
Location:	Artesia, MS			Birmingham, AL		
Research Cement No & Type:	RC-688, I, LA			RC-705, II, LA, HH		
Autoclave Expansion, 20% Replacement, %	0.01			0.08		
% Replace of Cement by Volume	0	30	60	0	30	60
Heat of Hydration, 7 days, Cal/gm	84.8	80	51	67.7	63	27
Heat of Hydration, 28 days, Cal/gm	96.5	93	79	78.8	78	50
Compressive Strength, 3 days psi	2880	2200	880	1700	1240	30
Compressive Strength, 7 days psi	4080	3300	1650	2510	2120	120
Compressive Strength, 28 days psi	5320	4900	2740	4040	3620	1780
Compressive Strength, 90 days psi	5860	7010	4680	5760	6690	3520
Compressive Strength, 180 days psi	6050	7180	5660	5990	7120	
Compressive Strength, 1 year psi		7210	6280		7680	
Water - Cement Ratio	0.485	0.464	0.435	0.485	0.460	0.4S
Flow %	111	108	134	122	118	13

Pozzolanic Activity Index, ASTM C618

With Lime @ 7 days PSI 1270

With Portland Cement (RC-688) at 28 days percent of Control 111

Tests for Pozzolan Hydraulic Activity

Compressive Strength (PSI)

W/C	3days	7days	28days
0.410	170		

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Chief, Cement & Pozzolan Test Branch

Table 16

Test Data for AD-570

Structures Laboratory USAE Waterways Exp St ATTN: Cem & Pozz Test Br P. O. Box 631 Vicksburg, MS 39180	REPORT OF TESTS ON POZZOLAN	Report No: Admixture No: AD 570 Date:

POZZOLAN CLASS: F	DESCRIPTION: Fly Ash	
COMPANY: Trinity	LOCATION: Purvis, MS	
MEMO NO: 1985	DATE: 10/6/75	JOB NO: 545-C-530
MEMO SUBJECT: Variations in Cementitious Media		

CHEMICAL COMPOSITION

SiO_2 %	47.81	Moisture Content %	0.16	Cr_2O_3 %	
Al_2O_3 %	30.61	LOI, % (750 C)	3.70	Chloride %	
Fe_2O_3 %	7.59	LOI, % (1000 C)			
MgO %	1.11	TiO_2 %			
SO_3 %	0.60	P_2O_5 %			
CaO %	2.14	Mn_2O_3 %			

Alkalies %	Water Soluble	Available (C-618)	Acid Soluble	Total Alkali
Na_2O %		0.12		0.37
K_2O %		0.94		2.78
Total as Na_2O%		0.74		2.20

PHYSICAL TESTS

Specific Gravity:	2.25	Fineness	% retained on 325 Sieve
Surface Area:	13,750	sqcm/cc, porosity	e = 0.519

Tests with portland cement cured @ 73.4 $\pm$ 3 F

Portland Cement Co:	United			Citadel		
Location:	Artesia, MS			Birmingham, AL		
Research Cement No & Type:	RC-688 (3)			RC-705, II, LA, HH		
Autoclave Expansion, 20% Replacement, %				0.03		
% Replace of Cement by Volume	0	30	60	0	30	60
Heat of Hydration, 7 days, Cal/gm						
Heat of Hydration, 28 days, Cal/gm						
Compressive Strength, 3 days psi	2950	2050	590	1700	960	
Compressive Strength, 7 days psi	4390	2920	1140	2510	1840	
Compressive Strength, 28 days psi	6030	4430	2060	4040	3700	
Compressive Strength, 90 days psi	6550	6010	3610	5760	5790	
Compressive Strength, 180 days psi	7230			5990		
Compressive Strength, 365 days psi	6790					
Water - Cement Ratio	0.485	0.513	0.552	0.485	0.500	
Flow	114	112	105	122	115	

Lime Pozz Str 175ml H20 Flow 106% 1550 psi
Pozzolanic Acitivity Index with Portland Cement (RC-705)
Portland Cement Compressive Strength 4590 psi (Control)
Portland Cement + Pozzolan Compressive Strength 5280 psi (115% of Control)

W. G. MILLER
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Chief, Cement & Pozzolan Test Branch

Table 17

Test Data for AD-518

Structures Laboratory USAE Waterways Exp St ATTN: Cem & Pozz Test Br P. O. Box 631 Vicksburg, MS 39180	REPORT OF TESTS ON POZZOLAN	Report No: Admixture No: AD 518 Date:

POZZOLAN CLASS: N	DESCRIPTION: Natural
COMPANY: Superior Prod	LOCATION: Hallelujah Junction, CA
MEMO NO: 1985 DATE: 10/6/75	JOB NO: 545-C-530
MEMO SUBJECT: Variations in Cementitious Media	

CHEMICAL COMPOSITION

SiO_2 %	67.98	Moisture Content %	1.37	Cr_2O_3 %	
Al_2O_3 %	17.40	LOI, % (750°C)	1.58	Chloride %	
Fe_2O_3 %	5.49	LOI, % (1000°C)			
MgO %	0.80	TiO_2 %			
SO_3 %	0.88	P_2O_5 %			
CaO %	2.28	Mn_2O_3 %			

Alkalies	Water Soluble	Available (C-618)	Acid Soluble	Total Alkali
Na_2O %	0.02	0.18	0.16	2.11
K_2O %	0.00	0.26	0.19	1.59
Total as Na_2O %	0.02	0.35	0.28	3.16

PHYSICAL TESTS

Specific Gravity: 2.39 | Fineness: % retained on 325 Sieve

Surface Area: 26,760 sqcm/cc, porosity e= 0.668

Tests with portland cement cured @ 73.4 ± 3° F

Portland Cement Co.:	United			Citadel		
Location:	Artesia, MS			Birmingham, AL		
Research Cement No & Type:	RC-688, I, LA			RC-705, II, LA, HH		
Autoclave Expansion, 20% Replacement, %	0.03			0.06		
% Replace of Cement by Volume	0	30	60	0	30	60
Heat of Hydration, 7 days, Cal/gm	84.8	75	59	67.7	60	46
Heat of Hydration, 28 days, Cal/gm	96.5	86	68	78.8	72	61
Compressive Strength, 3 days psi	2880	2710	1120	1700	1710	920
Compressive Strength, 7 days psi	4080	3920	1880	2510	2480	1480
Compressive Strength, 28 days psi	5320	6050	4010	4040	4930	3640
Compressive Strength, 90 days psi	5860	6780	6350	5760	5540	4860
Compressive Strength, 180 days psi	6050	7330	7240	5990	5620	5380
Compressive Strength, 1 year psi		7690	7250		5880	5460
Water - Cement Ratio	0.485	0.485	0.532	0.485	0.485	0.532
Flow %	111	51	40	122	62	62

Pozzolanic Activity Index, ASTM C618
With Lime @ 7 days PSI 1960
With Portland Cement (RC-688) at 28 days percent of Control 98

W. G. MILLER
Chemist
Chief, Cement & Pozzolan Test Branch

Table 18

Test Data for AD-536

Structures Laboratory USAE Waterways Exp St ATTN: Cem & Pozz Test Br P. O. Box 631 Vicksburg, MS 39180	REPORT OF TESTS ON POZZOLAN	Report No: Admixture No: AD 536 Date:

POZZOLAN CLASS:	DESCRIPTION: Amorphous Silica Spheres	
COMPANY: Reynolds Aluminum	LOCATION: Sheffield, AL	
MEMO NO: 1985	DATE: 10/6/75	JOB NO: 545-C-530
MEMO SUBJECT: Variations in Cementitious Media		

CHEMICAL COMPOSITION

SiO_2 %	95.98	Moisture Content %	0.27	Cr_2O_3 %	
Al_2O_3 %	1.26	LOI, % (750°C)	1.13	Chloride %	
Fe_2O_3 %	0.12	LOI, % (1000°C)			
MgO %	0.03	TiO_2 %			
SO_3 %	0.12	P_2O_5 %			
CaO %	0.26	Mn_2O_3 %			

Alkalies %	Water Soluble	Available (C-618)	Acid Soluble	Total Alkali
Na_2O %		0.06	0.03	0.15
K_2O %		0.03	0.00	0.24
Total as Na_2O%		0.08	0.03	0.31

PHYSICAL TESTS

Specific Gravity: 2.22	Fineness % retained on 325 Sieve
Surface Area: 58700 sqcm/cc, porosity e =	
Tests with portland cement cured @ 73.4 ± 3°F	

Portland Cement Co:	United			Citadel		
Location:	Artesia, MS			Birmingham, AL		
Research Cement No & Type:	RC-688 I, LA			RC-705, II, LA, HH		
Autoclave Expansion, 20% Replacement, %						
% Replace of Cement by Volume	0	30	60	0	30	60
Heat of Hydration, 7 days, Cal/gm	84.8	73	56	67.7	61	52
Heat of Hydration, 28 days, Cal/gm	96.5	90	78	78.8	74	58
Compressive Strength, 3 days psi	2880	1280*		1700		
Compressive Strength, 7 days psi	4080	4180		2510		
Compressive Strength, 28 days psi	5320	6860		4040		
Compressive Strength, 90 days psi	5860			5760		
Compressive Strength, 180 days psi	6050			5990		
Compressive Strength, 365 days psi						
Water - Cement Ratio	0.485			0.485		
Flow	111			122		

* 1 day strength

Lime Pozzolan strength, 360 Ml H_2O, Flow 99% 1170 PSI

W. G. MILLER
Chemist
Chief, Cement & Pozzolan Test Branch

Table 19

Test Data for AD-536(2)

Structures Laboratory USAE Waterways Exp St ATTN: Cem & Pozz Test Br P. O. Box 631 Vicksburg, MS 39180	REPORT OF TESTS ON POZZOLAN	Report No: Admixture No: AD536(2) Date:

POZZOLAN CLASS:		DESCRIPTION: Amorphous Silica Spheres	
COMPANY: Reynolds Aluminum		LOCATION: Sheffield, AL	
MEMO NO: 1985	DATE: 10/6/75	JOB NO: 545-C-530	
MEMO SUBJECT: Variations in Cementitious Media			

CHEMICAL COMPOSITION

SiO_2 %	93.90	Moisture Content %	0.38	Cr_2O_3 %	0.00
Al_2O_3 %	0.70	LOI, % (750°C)	0.99	Chloride %	0.01
Fe_2O_3 %	0.00	LOI, % (1000°C)	1.16		
MgO %	1.20	TiO_2 %			
SO_3 %	0.20	P_2O_5 %			
CaO %	0.78	Mn_2O_3 %	0.00		

Alkalies %	Water Soluble	Available (C-618)	Acid Soluble	Total Alkali
Na_2O %		0.03		0.15
K_2O %		0.04		0.24
Total as Na_2O%		0.07		0.31

PHYSICAL TESTS

Specific Gravity: 2.22	Fineness	% retained on 325 Sieve
Surface Area: 98,900	sqcm/cc, porosity	e = 0.714

Tests with portland cement cured @ 73.4 ± 3°F

Portland Cement Co:	United			Citadel		
Location:	Artesia, MS			Birmingham, AL		
Research Cement No & Type:	RC-688(3) I, LA			RC-705, II, LA, HH		
Autoclave Expansion, 20% Replacement, %						
% Replace of Cement by Volume	0	30	60	0	30	60
Heat of Hydration, 7 days, Cal/gm						
Heat of Hydration, 28 days, Cal/gm						
Compressive Strength, 3 days psi	3710*	2430	640	1700	1160	[illegible]
Compressive Strength, 7 days psi	4390	3890	1750	2510	2950	[illegible]
Compressive Strength, 28 days psi	6030	7030	4210	4040	5460	[illegible]
Compressive Strength, 90 days psi	6550	8870	[illegible]	5760	6740	[illegible]
Compressive Strength, 180 days psi	7230	8990	5360	5990	6520	[illegible]
Compressive Strength, 365 days psi	6790	8880	5540		[illegible]	[illegible]
Water - Cement Ratio		0.546	0.782		0.546	0.782
Flow		64	48		86	72

Lime-Pozzolan Strength cured 24 hrs @ 73.4 ± 3°F, 6 days @ 130 ± 3°F: 1870 psi 200gm pozz + 100 gm lime & 375ml H_2O, Flow 88.

Pozzolanic Activity Index, ASTM C618
With Portland Cement (RC-688) at 28 days percent of Control 145

W. G. MILLER
Chemist
Chief, Cement & Pozzolan Test Branch

Table 20

Length Changes of Mortar Bars Made with Low-Alkali Cements RC-688* with 10 Different Pozzolans** or No Pozzolan

Bar No.	No Pozzolan		30% Fly Ash AD-505	30% Fly Ash AD-506	30% Fly Ash AD-507	30% Fly Ash AD-509	30% Fly Ash AD-510	30% Fly Ash AD-511	30% Fly Ash AD-512	30% Fly Ash AD-513	30% Lassenite AD-518	30% Silica Fume AD-536
	Length Changes at 14-Day Age, % — Cement RC-688 with											
1	0.078	0.130	0.015	0.020	0.023	0.122	0.316	0.018	0.041	0.133	0.001	-0.007
2	0.063	0.128	0.014	0.018	0.020	0.124	0.315	0.016	0.054	0.093	0.002	-0.007
3	0.088	0.111	0.013	0.019	0.017	0.115	0.316	0.018	0.039	0.088	0.000	-0.009
4		0.087										
5		0.074										
6		0.071										
Average	0.076†	0.100	0.014	0.019	0.020	0.120	0.316	0.017	0.045	0.105	0.001	-0.008
1††		0.127					0.299			0.093		
2††		0.137					0.306			0.096		
3††		0.159					0.302			0.077		
Average		0.141					0.302			0.089		
Overall Average, 12 bars		0.104					0.309			0.097		

* 0.44 percent as Na_2O.

** Made in accordance with ASTM C 441/CRD-C 257 (WES 1949). Aggregate was Pyrex glass. Each bar of a set was in a different container unless indicated otherwise.

† These three bars were in one container.

†† Read at 15-day age; average interpolated to 14-day age.

Table 21

Length Change of Mortar Bars Made with High-Alkali Cements* RC-720 or RC-725 and Different Amounts of 10 Pozzolans** or No Pozzolan

Bar No.	Length Change at 14-Day Age, % — Cement RC-720 with: No Pozzolan		30% Fly Ash AD-505	30% Fly Ash AD-506	30% Fly Ash AD-507	30% Fly Ash AD-509	30% Fly Ash AD-510	30% Fly Ash AD-511	30% Fly Ash AD-512	30% Fly Ash AD-513	30% Lassenite AD-518	30% Silica Fume AD-536
1	0.344	0.270	0.063	0.109	0.071	0.130	0.305	0.082	0.093	0.119	0.009	-0.010
2	0.287	0.268	0.060	0.092	0.059	0.132	0.305	0.079	0.105	0.119	0.008	-0.009
3	0.337	0.257	0.060	0.082	0.047	0.131	0.301	0.077	0.087	0.117	0.006	-0.010
4		0.254										
5		0.258										
6		0.243										
Average	0.323†	0.258	0.061	0.094	0.059	0.131	0.304	0.079	0.095	0.118	0.008	-0.010
	Cement RC-725 with: No Pozzolan††		25% AD-505	50% AD-506	25% AD-507	50% AD-509	50% AD-510	50% AD-511	50% AD-512	50% AD-513	25% AD-518	15% AD-536
1		0.340	0.103	0.051	0.100	0.071	0.211	0.029	0.081	0.063	0.021	-0.001
2		0.358	0.098	0.041	0.094	0.072	0.196	0.035	0.075	0.067	0.017	-0.002
3		0.366	0.097	0.039	0.091	0.075	0.198	0.033	0.081	0.068	0.017	-0.002
4		0.292										
5		0.326										
6		0.304										
Average		0.331	0.099	0.044	0.095	0.073	0.202	0.032	0.079	0.066	0.018	-0.002
Overall Average, 15 bars		0.300										

* RC-720, 0.79 percent as Na_2O; RC-725, 0.78 percent as Na_2O.

** Made in accordance with ASTM C 441/CRD-C 257 (WES 1949). Aggregate was Pyrex glass. Each bar of a set was in a different container unless indicated otherwise.

† These three bars were in one container.

†† Read at 15-day age; average interpolated to 14-day age.

Table 22

Length Change of Mortar Bars Made with High-Alkali Cements* RC-756 and Different Amounts of 10 Pozzolans** or No Pozzolan

Bar No.	Length Change at 14-Day Age, % Cement RC-756 with No Pozzolan		30% Fly Ash AD-505	30% Fly Ash AD-506	30% Fly Ash AD-507	30% Fly Ash AD-509	30% Fly Ash AD-510	30% Fly Ash AD-511	30% Fly Ash AD-512	30% Fly Ash AD-513	30% Lassenite AD-518	30% Silica Fume AD-536
1	0.390	0.404	0.162	0.209	0.144	0.197	0.314	0.165	0.150	0.196	0.031	-0.016
2	0.365	0.408	0.160	0.204	0.140	0.214	0.319	0.149	0.134	0.187	0.032	-0.011
3	0.390	0.411	0.159	0.216	0.150	0.193	0.343	0.151	0.158	0.188	0.030	-0.012
4		0.406										
5		0.394										
6		0.412										
Average	0.382†	0.406	0.160	0.210	0.145	0.201	0.325	0.155	0.147	0.190	0.031	-0.013
	Cement RC-756 with											
	No Pozzolan		50% AD-505	50% AD-506	50% AD-507	50% AD-509	50% AD-510	50% AD-511	50% AD-512	50% AD-513	25% AD-518	15% AD-536
1		0.339	0.092	0.143	0.093	0.136	0.160	0.091	0.106	0.154	0.047	0.008
2		0.349	0.101	0.130	0.100	0.128	0.155	0.092	0.113	0.136	0.044	0.009
3		0.400	0.093	0.137	0.091	0.125	0.159	0.094	0.106	0.121	0.050	0.013
4		0.419										
5		0.359										
6		0.380										
Average		0.374	0.095	0.137	0.095	0.130	0.158	0.092	0.108	0.137	0.047	0.010
Overall Average, 15 bars		0.388										

* 1.16 percent as Na_2O.
** Made in accordance with ASTM C 441/CRD-C 257 (WES 1949). Aggregate was Pyrex glass. Each bar of a set was in a different container unless indicated otherwise.
† These three bars were in one container.

Table 23

Reduction in Expansion Data

	Reduction in Expansion,* %, with Cement							
	RC-688 and 30% Admixture		RC-725 and 25% Admixture	RC-720 and 30% Admixture	RC-725 and 50% Admixture	RC-756 and 25% Admixture	RC-756 and 30% Admixture	RC-756 and 50% Admixture
Fly Ashes	R_E	R_E	R_E	R_E	R_E	R_E	R_E	R_E
AD-505	85		70	78			60	75
AD-506	79			66	86		47	64
AD-507	78		71	79			64	75
AD-509	No reduction			53	78		50	65
AD-510	No reduction	No reduction		No reduction	38		18	58
AD-511	82			72	90		61	76
AD-512	51			66	76		63	71
AD-513	No reduction	18		58	80		52	64
Natural Pozzolan								
AD-518	99		94	97		88	92	
Silica Fume								
AD-536	>100		>100**	>100		97**	>100	

* Modified version of ASTM C 441/CRD-C 257 (WES 1949); $R_E = (E_r - E_t) \times 100/E_r$; based on length-change data.

** Used 15 percent instead of 25 percent.

Table 24

Length Change of Mortar Bars Made with Different Amounts of Pyrex Glass (CL-3 G-1) and Low-Alkali Portland Cement RC-688(2)*

Fine Aggregate Combination	Bar No.	Length Change, %, at Ages Shown Below, days 14	21	28	56
2% Pyrex	1	0.005	0.005	0.007	0.007
98% Limestone	2	0.004	0.000	0.001	0.005
(CRD-MS-28)	3	0.003	0.003	0.004	0.004
	Average	0.004	0.003	0.004	0.005
5% Pyrex	1	0.003	0.003	0.005	0.007
95% Limestone	2	0.004	0.004	0.005	0.007
(CRD-MS-28)	3	0.005	0.006	0.007	0.010
	Average	0.004	0.004	0.006	0.008
8% Pyrex	1	0.006	0.007	0.007	0.011
92% Limestone	2	0.008	0.006	0.007	0.010
(CRD-MS-28)	3	0.005	0.005	0.006	0.008
	Average	0.006	0.006	0.007	0.010
100% Pyrex	1	0.080	0.127	0.165	0.195
	2	0.065	0.098	0.131	0.155
	3	0.069	0.112	0.153	0.198
	Average	0.071	0.112	0.150	0.183

* 0.37 percent alkali as Na_2O. Bars made in accordance with ASTM C 441/ CRD-C 257 (WES 1949).

Table 25

Length Change of Mortar Bars Made with Different Amounts of Pyrex Glass (CL-3 G-1) and High-Alkali Portland Cement RC-725*

Fine Aggregate Combination	Bar No.	Length Change, %, at Ages Shown Below, days 14	21	28	56
2% Pyrex	1	0.017	0.019	0.020	0.028
98% Limestone	2	0.015	0.016	0.017	0.023
(CRD-MS-28)	3	0.007	0.008	0.009	0.014
	Average	0.013	0.014	0.015	0.022
5% Pyrex	1	0.018	0.020	0.022	0.027
95% Limestone	2	0.020	0.020	0.021	0.029
(CRD-MS-28)	3	0.020	0.021	0.023	0.029
	Average	0.019	0.020	0.022	0.028
8% Pyrex	1	0.020	0.022	0.025	0.040
92% Limestone	2	0.021	0.024	0.027	0.034
(CRD-MS-28)	3	0.022	0.025	0.027	0.034
	Average	0.021	0.024	0.026	0.036
100% Pyrex	1	0.305	0.361	0.380	0.400
	2	0.308	0.352	0.375	0.405
	3	0.311	0.348	0.370	0.400
	Average	0.308	0.354	0.375	0.402

* 0.78 percent alkali as Na_2O. Bars made in accordance with ASTM C 441/ CRD-C 257 (WES 1949).

Table 26

Length Change of Mortar Bars Made with Different Amounts of Pyrex Glass (CL-3 G-1) and High-Alkali Portland Cement RC-761*

Fine Aggregate Combination	Bar No.	Length Change, %, at Ages Shown Below, days 14	21	28	35	56
2% Pyrex	1	Broken				
98% Limestone	2	0.016	0.018	0.019	0.022	0.030
(CRD-MS-28)	3	0.016	0.018	0.019	0.022	0.026
	4	0.015	0.017	0.018	0.021	0.024
	5	0.019	0.018	0.019	0.022	0.026
	6	0.018	0.019	0.020	0.023	0.026
	Average	0.017	0.018	0.019	0.022	0.026
5% Pyrex	1	0.024	0.026	0.031	**	0.039
95% Limestone	2	0.024	0.027	0.030		0.038
(CRD-MS-28)	3	0.032	0.027	0.031		0.039
	Average	0.024	0.027	0.031		0.039
8% Pyrex	1	0.032	0.039	0.047	**	0.082
92% Limestone	2	0.032	0.040	0.048		0.079
(CRD-MS-28)	3	0.032	0.040	0.048		0.086
	Average	0.032	0.040	0.048		0.082
100% Pyrex	1	0.373	0.428	0.448	0.473	0.503
	2	0.373	0.434	0.453	0.478	0.511
	3	0.365	0.429	0.457	0.486	0.515
	1(A)	0.382	0.453	0.490	**	0.608
	2(A)	0.383	0.457	0.486		0.542
	3(A)	0.356	0.439	0.467		0.505
	Average	0.372	0.440	0.467	0.479	0.531

* 1.07 percent alkali as Na_2O. Bars made in accordance with ASTM C 441/ CRD-C 257 (WES 1949).

** Not determined.

Table 27

Length Change of Mortar Bars Made with Different Amounts of Beltane Opal (CL-4 G-1) and Low-Alkali Portland Cement RC-688*

Fine Aggregate Combination	Bar No.	Length Change, %, at Ages Shown Below, days				
		7	14	21	28	56
2% Opal	1	0.002	0.004	0.007	0.007	0.010
98% Limestone	2	-0.001	0.005	0.007	0.008	0.011
(CRD-MS-28)	3	0.000	0.005	0.007	0.007	0.009
	Average	0.000	0.005	0.007	0.007	0.010
4% Opal	1	-0.001	0.003	0.004	0.005	0.006
96% Limestone	2	0.000	0.002	0.004	0.004	0.006
(CRD-MS-28)	3	-0.002	0.002	0.004	0.004	0.008
	Average	-0.001	0.002	0.004	0.004	0.007
6% Opal	1	-0.002	0.001	0.003	0.002	0.006
94% Limestone	2	-0.003	0.000	0.002	0.005	0.006
(CRD-MS-28)	3	-0.002	0.000	0.001	0.000	0.004
	Average	-0.002	0.001	0.002	0.002	0.005
100% Opal	1	0.005	0.011	0.012	0.013	0.017
	2	0.005	0.011	0.014	0.015	0.018
	3	0.004	0.009	0.012	0.014	0.018
	Average	0.005	0.010	0.013	0.014	0.018

* 0.44 percent alkali as Na_2O. Bars made in accordance with ASTM C 441/ CRD-C 257 (WES 1949).

Table 28

Length Change of Mortar Bars Made with Different Amounts of Beltane Opal (CL-4 G-1) and High-Alkali Portland Cement RC-725*

Fine Aggregate Combination	Bar No.	Length Change, %, at Ages Shown Below, days					
		7	14	21	28	56	90
1% Opal	1		0.045	0.064	0.070	0.087	0.095
99% Limestone	2	**	0.036	0.055	0.067	0.079	0.087
(CRD-MS-28)	3		0.051	0.072	0.079	0.095	0.103
	Average		0.044	0.064	0.072	0.087	0.095
2% Opal	1	0.019	0.038	0.062	0.063	0.070	
98% Limestone	2	0.020	0.051	0.073	0.085	0.096	**
(CRD-MS-28)	3	0.022	0.050	0.069	0.081	0.088	
	Average	0.020	0.046	0.068	0.076	0.085	
4% Opal	1	0.012	0.021	0.024	0.025	0.030	
96% Limestone	2	0.012	0.023	0.027	0.029	0.033	**
(CRD-MS-28)	3	0.014	0.022	0.025	0.025	0.030	
	Average	0.013	0.022	0.025	0.026	0.031	
6% Opal	1	0.011	0.017	0.018	0.019	0.022	
94% Limestone	2	0.010	0.017	0.021	0.022	0.025	**
(CRD-MS-28)	3	0.011	0.017	0.020	0.021	0.020	
	Average	0.011	0.017	0.020	0.021	0.022	
100% Opal	1	0.008	0.016	0.022	0.024	0.030	
	2	0.008	0.018	0.021	0.023	0.029	**
	3	0.009	0.017	0.022	0.024	0.030	
	Average	0.008	0.017	0.022	0.024	0.030	

* 0.78 percent alkali as Na_2O. Bars made in accordance with ASTM C 441/ CRD-C 257 (WES 1949).

** Not determined.

Table 29

Length Change of Mortar Bars Made with Different Amounts of Beltane Opal (CL-4 G-1) and High-Alkali Cements RC-756 or RC-761*

Cement-Fine Aggregate Combination	Bar No.	Length Change, %, at Ages Shown Below, days					
		7	14	21	28	56	90
1% Opal	1		0.071	0.081	0.083	0.096	0.101
99% Limestone	2	**	0.072	0.081	0.084	0.089	0.096
(CRD-MS-28)	3		0.066	0.070	0.073	0.080	0.087
(RC-756)	Average		0.070	0.077	0.080	0.088	0.095
2% Opal	1	0.115	0.152	0.165	0.175	0.188	
98% Limestone	2	0.121	0.161	0.170	0.182	0.204	**
(CRD-MS-28)	3	0.125	0.167	0.185	0.192	0.206	
(RC-761)	Average	0.120	0.160	0.173	0.183	0.199	
4% Opal	1	0.137	0.208	0.212	0.214	0.221	
96% Limestone	2	0.117	0.178	0.183	0.184	0.190	**
(CRD-MS-28)	3	0.119	0.185	0.190	0.191	0.198	
(RC-761)	Average	0.124	0.190	0.195	0.196	0.203	
6% Opal	1	0.092	0.119	0.123	0.124	0.130	
94% Limestone	2	0.055	0.087	0.090	0.090	0.095	**
(CRD-MS-28)	3	0.072	0.099	0.099	0.100	0.106	
(RC-761)	Average	0.073	0.102	0.104	0.105	0.110	
100% Opal	1	0.006	0.014	0.017	0.018	0.023	
(RC-761)	2	0.006	0.013	0.016	0.018	0.022	**
	3	0.007	0.014	0.016	0.018	0.022	
	Average	0.006	0.014	0.016	0.018	0.022	

* 1.16 percent alkali as Na_2O in RC-756; 1.07 percent alkali as Na_2O in RC-761. Bars made in accordance with ASTM C 441/CRD-C 257 (WES 1949).

** Not determined.

Table 30

Chemical Analysis of Beltane Opal*

	Composite of CL-4 G-1**	Slab No. 1†
SiO_2	93.26	70.54
Al_2O_3	1.69	5.96
Fe_2O_3	0.24	0.09
CaO	0.16	0.23
MgO	<0.01	<0.01
Na_2O	0.13	0.43
K_2O	0.12	1.72
Total as Na_2O	0.21	1.56
SO_3	0.40	8.90
Ignition loss, 950° C	3.66	11.67
Total	99.66	99.54

* Samples were dried at 110° C to remove all free water before analysis. Silicon dioxide and sulfur trioxide were determined gravimetrically by fusing portions of the samples with sodium carbonate. The other oxides were determined by an AA after fusing the samples with lithium metaborate.

** Minus No. 100-mesh material.

† Had alunite peaks at 5.8 and 5.0 Å by XRD.

Table 31

Length Change of Mortar Bars Made with Different Amounts of Glassy Igneous Rock (CL-28 MS-1) and High-Alkali Cement RC-725*

Fine Aggregate Combination	Bar No.	Length Change, %, at Ages Shown Below, days: 7	14	21	28	56	90
3% Glassy Igneous Rock, 97% Limestone†	1	0.011	0.017	0.024	0.025	0.030	
	2	0.017	0.027	0.031	0.032	0.038	**
	3	0.011	0.020	0.025	0.026	0.032	
	4	0.017	0.020	0.026	0.029	0.032	
	Average	0.014	0.021	0.026	0.028	0.033	
6% Glassy Igneous Rock, 94% Limestone†	1	0.016	0.073	0.107	0.133	0.182	
	2	0.012	0.022	0.030	0.035	0.048	**
	3	0.016	0.025	0.035	0.037	0.048	
	4	0.021	0.087	0.127	0.158	0.225	
	Average	0.016	0.052	0.075	0.091	0.126	
12% Glassy Igneous Rock, 88% Limestone†	1	0.025	0.037	0.051	0.055	0.065	
	2	0.019	0.060	0.097	0.130	0.209	**
	3	0.025	0.044	0.052	0.055	0.064	
	4	0.015	0.054	0.088	0.115	0.185	
	Average	0.021	0.049	0.072	0.089	0.131	
100% Glassy Igneous Rock	1	0.018	0.038	0.049	0.049	0.061	0.061
	2	0.017	0.037	0.048	0.050	0.064	0.065
	3	0.019	0.037	0.047	0.051	0.061	0.061
	4	0.018	0.037	0.046	0.051	0.059	0.060
	Average	0.018	0.037	0.048	0.050	0.061	0.062

* 0.78 percent alkali as Na_2O. Bars made in accordance with ASTM C 227/CRD-C 123 (WES 1949).

** Not determined.

† A mixture of CRD-MS-28 and CL-2 MS-1(3).

Table 32

Length Change of Mortar Bars Made with Different Amounts of Glassy Igneous Rock (CL-28 MS-1) and High-Alkali Portland Cement RC-756(2)*

Fine Aggregate Combination	Bar No.	Length Change, %, at Ages Shown Below, days: 7	14	21	28	56	90
5% Glassy Igneous Rock, 95% Limestone†	1	0.046	0.107	0.127	0.138	0.150	
	2	0.049	0.110	0.137	0.146	0.159	**
	3	0.017	0.036	0.049	0.064	0.112	
	4	0.015	0.035	0.055	0.075	0.143	
	Average	0.032	0.072	0.092	0.106	0.141	
10% Glassy Igneous Rock, 90% Limestone†	1	0.029	0.103	0.143	0.181	0.271	
	2	0.028	0.093	0.135	0.170	0.250	**
	3	0.039	0.124	0.173	0.213	0.299	
	4	0.039	0.136	0.188	0.231	0.321	
	Average	0.034	0.114	0.160	0.199	0.285	
20% Glassy Igneous Rock, 80% Limestone†	1	0.072	0.192	0.246	0.288	0.360	
	2	0.056	0.156	0.208	0.242	0.312	**
	3	0.055	0.156	0.209	0.244	0.309	
	4	0.075	0.197	0.252	0.297	0.384	
	Average	0.064	0.175	0.229	0.268	0.341	
40% Glassy Igneous Rock, 60% Limestone†	1	0.085	0.232	0.284	0.309	0.363	
	2	0.103	0.189	0.279	0.305	0.347	**
	3	0.094	0.218	0.262	0.282	0.321	
	4	0.107	0.252	0.298	0.330	0.364	
	Average	0.097	0.223	0.281	0.306	0.349	
100% Glassy Igneous Rock	1	0.057	0.096	0.154	0.180	0.239	0.242
	2	0.035	0.106	0.159	0.184	0.240	0.244
	3	0.030	0.075	0.100	0.112	0.144	0.144
	4	0.002	0.026	0.118	0.134	0.167	0.167
	Average	0.031	0.090	0.133	0.154	0.198	0.199

* 1.31 percent alkali as Na_2O. Bars made in accordance with ASTM C 227/ CRD-C 123 (WES 1949).

** Not determined.

† A mixture of CRD-MS-28 and CL-2 MS-1(3).

Table 33

Chemical Analysis of Glassy Igneous Rock (CL-28 MS-1)*

Major Oxides**	Percent by Weight Run 1	Run 2	Average
SiO_2	67.12	66.98	67.05
Al_2O_3	17.23	17.78	17.51
Fe_2O_3	2.43	2.50	2.47
CaO	4.79	4.63	4.71
MgO	0.65	0.64	0.65
Na_2O	3.87	3.84	3.86
K_2O	1.80	1.80	1.80
MnO	0.07	0.07	0.07
TiO_2	0.10	0.09	0.10
P_2O_5	0.08	0.08	0.08
Loss on Ignition, 1,000° C	0.71	--	0.71
			99.01

* A portion was ground to pass a No. 100 sieve; two subsamples were then analyzed.

** All oxides except TiO_2 and P_2O_5 were determined by AA on a sample fused with lithium metaborate; the fusion was then dissolved by 1:3 HCl acid. Titanium dioxide was determined by AA using the solution prepared for alkali analysis. The P_2O_5 was determined with a colorimeter using an acid solution by ASTM C 114/CRD-C 209 (WES 1949).

Table 34

Length Change of Mortar Bars Made with 80 Percent Reactive Chert (CL-22 MS-1), High-Alkali Portland Cement RC-725,* and Different Amounts of Pozzolans**

Pozzolan	Bar No.	Length Change, %, at Ages Shown Below, days						
		7	14	21	28	56	90	108
None	2	0.008	0.022	0.015	0.016	0.017	0.025	0.018
	3	0.003	†	--	--	--	--	--
	4	0.005	0.017	0.012	0.014	0.015	0.024	0.016
	1	0.009	0.019	0.015	0.015	0.018	0.025	0.018
	Average	0.006	0.019	0.014	0.015	0.017	0.025	0.017
30% AD-505	3	0.005	0.022	0.010	0.011	0.012	0.025	0.013
	4	0.009	0.024	0.012	0.013	0.013	0.025	0.015
	1	0.006	0.017	0.009	0.011	0.012	0.022	0.018
	2	0.007	0.016	0.009	0.009	0.011	0.020	0.013
	Average	0.007	0.020	0.010	0.011	0.012	0.023	0.015
50% AD-509	3	0.005	0.027	0.009	0.010	0.010	0.019	0.010
	1	0.010	0.025	0.014	0.014	0.014	0.020	0.012
	2	0.009	0.020	0.012	0.014	0.014	0.022	0.014
	4	0.005	0.018	0.008	0.008	0.009	0.016	0.008
	Average	0.007	0.022	0.011	0.012	0.012	0.019	0.011
10% AD-518	3	0.006	0.023	0.013	0.015	0.017	0.025	0.018
	1	0.008	0.023	0.013	0.016	0.017	0.027	0.018
	4	0.005	0.022	0.011	0.012	0.015	0.022	0.017
	2	0.005	0.023	0.012	0.015	0.016	0.022	0.013
	Average	0.006	0.023	0.012	0.014	0.016	0.024	0.016

* 0.78 percent alkali as Na_2O.
** Made and tested in accordance with ASTM C 227/CRD-C 123 (WES 1949).
† Insert came out of bar.

Table 35

Length Change of Mortar Bars Made with 80 Percent Reactive Chert (CL-22 MS-1), High-Alkali Portland Cement RC-756(2),* and Different Amounts of Pozzolans**

Pozzolan	Bar No.	Length Change, %, at Ages Shown Below, days: 7	14	21	28	56	90	108
None	3	0.004	0.020	0.011	0.009	0.009	0.014	0.006
	2	0.005	0.023	0.011	0.014	0.014	0.022	0.016
	1	0.007	0.018	0.012	0.016	0.017	0.025	0.018
	4	0.005	0.014	0.009	0.011	0.012	0.019	0.012
	Average	0.005	0.019	0.011	0.012	0.013	0.020	0.013
50% AD-505	1	0.003	0.022	0.010	0.012	0.014	0.026	0.015
	4	0.001	0.017	0.010	0.012	0.012	0.021	0.013
	2	0.006	0.020	0.011	0.014	0.015	0.025	0.016
	3	0.001	0.017	0.007	0.010	0.010	0.019	0.012
	Average	0.003	0.019	0.010	0.012	0.013	0.023	0.014
60% AD-509	1	0.004	0.019	0.009	0.011	0.011	0.021	0.012
	4	Broken---						
	3	0.003	0.022	0.008	0.011	0.011	0.021	0.012
	2	0.005	0.013	0.008	0.011	0.011	0.019	0.012
	Average	0.004	0.018	0.008	0.011	0.011	0.020	0.012
10% AD-518	4	0.004	0.023	0.009	0.012	0.012	0.019	0.013
	1	0.005	0.021	0.010	0.013	0.014	0.023	0.017
	3	0.004	0.015	0.010	0.014	0.015	0.024	0.015
	2	0.001	0.012	0.003	0.005	0.007	0.015	0.008
	Average	0.004	0.018	0.008	0.011	0.012	0.020	0.013

* 1.31 percent alkali as Na_2O.

** Made and tested in accordance with ASTM C 227/CRD-C 123 (WES 1949).

Table 36

Length Change of Mortar Bars Made with 1-1/2 Percent Reactive Opal (CL-4 G-1), High-Alkali Portland Cement RC-725,* and Different Amounts of Pozzolans**

Pozzolan	Bar No.	Length Change, %, at Ages Shown Below, days						
		7	14	21	28	56	90	113
No Pozzolan	3	0.017	0.035	0.042	0.043	0.050	0.063	0.066
	4	0.019	0.030	0.043	0.043	0.049	0.063	0.066
	2	0.018	0.034	0.045	0.045	0.054	0.069	0.076
	1	0.018	0.037	0.045	0.045	0.058	0.082	0.085
	Average	0.018	0.034	0.044	0.044	0.053	0.069	0.073
30% AD-505	2	0.015	0.018	0.020	0.020	0.016	0.017	0.020
	4	0.011	0.012	0.017	0.016	0.014	0.017	0.019
	1	0.013	0.015	0.017	0.017	0.015	0.019	0.021
	3	0.015	0.016	0.019	0.018	0.016	0.020	0.021
	Average	0.014	0.015	0.018	0.018	0.015	0.018	0.020
50% AD-509	3	0.013	0.013	0.013	0.013	0.012	0.011	0.013
	4	0.010	0.010	0.011	0.011	0.007	0.009	0.012
	1	0.011	0.014	0.015	0.014	0.011	0.013	0.013
	2	0.012	0.015	0.017	0.015	0.015	0.016	0.017
	Average	0.012	0.013	0.014	0.013	0.011	0.012	0.014
10% AD-518	2	0.017	0.027	0.051	0.075	0.164	0.194	0.197
	1	0.017	0.020	0.033	0.058	0.175	0.224	0.273
	3	0.016	0.025	0.033	0.040	0.119	0.138	0.146
	4	0.015	0.022	0.027	0.025	0.045	0.080	0.105†
	Average	0.016	0.024	0.036	0.050	0.153	0.185	0.205

* 0.78 percent alkali as Na_2O.
** Made and tested in accordance with ASTM C 227/CRD-C 123 (WES 1949).
† Value not included in average.

Table 37

Length Change of Mortar Bars Made with 3 Percent Reactive Opal (CL-4 G-1), High-Alkali Portland Cement RC-756(2),* and Different Amounts of Pozzolans**

Pozzolan	Bar No.	Length Change, %, at Ages Shown Below, days						
		7	14	21	28	56	90	113
No Pozzolan	4	0.076	0.111	0.130	0.130	0.143	0.211	0.217
	1	0.073	0.095	0.129	0.135	0.160	0.196	0.228
	2	0.073	0.091	0.142	0.144	0.154	0.179	0.189
	3	0.072	0.101	0.109	0.110	0.146	0.174	0.176
	Average	0.074	0.100	0.128	0.130	0.152	0.190	0.202
50% AD-505	4	0.007	0.012	0.012	0.012	0.006	0.010	0.012
	3	0.014	0.014	0.014	0.013	0.009	0.013	0.016
	1	0.010	0.010	0.010	0.010	0.005	0.008	0.008
	2	0.004	0.010	0.010	0.010	0.009	0.011	0.012
	Average	0.009	0.012	0.012	0.011	0.007	0.010	0.012
60% AD-509	3	0.013	0.013	0.014	0.014	0.007	0.008	0.010
	4	0.009	0.011	0.012	0.012	0.009	0.011	0.012
	2	0.015	0.015	0.015	0.015	0.008	0.012	0.013
	1	0.013	0.013	0.013	0.013	0.008	0.012	0.012
	Average	0.012	0.013	0.014	0.014	0.008	0.011	0.012
10% AD-518	4	0.083	0.127	0.153	0.167	0.242	0.312	0.342
	2	0.078	0.115	0.145	0.165	0.248	0.307	0.332
	1	0.079	0.131	0.155	0.167	0.232	0.276	0.277
	3	0.076	0.220	0.245	0.262	0.339	0.387	0.395
	Average	0.079	0.148	0.174	0.190	0.265	0.320	0.336

* 1.31 percent alkali as Na_2O.

** Made and tested in accordance with ASTM C 227/CRD-C 123 (WES 1949).

Table 38

Length Change of Mortar Bars Made with 9 Percent Glassy Igneous Rock (CL-28 MS-1), High-Alkali Portland Cement RC-725,* and Different Amounts of Pozzolans**

Pozzolan	Bar No.	Length Change, %, at Ages Shown Below, days: 7	14	21	27	56	90	105
No Pozzolan	4	0.016	0.034	0.055	0.072	0.132	0.166	0.165
	1	0.013	0.029	0.050	0.069	0.140	0.175	0.176
	3	0.017	0.030	0.048	0.065	0.128	0.158	0.160
	2	0.016	0.033	0.054	0.073	0.143	0.173	0.173
	Average	0.016	0.032	0.052	0.070	0.136	0.168	0.168
30% AD-505	2	0.000	0.004	0.002	0.002	0.007	0.013	0.015
	1	0.002	0.005	0.002	0.002	0.008	0.014	0.015
	3	0.004	0.007	0.006	0.006	0.010	0.015	0.017
	4	0.003	0.005	0.005	0.005	0.008	0.013	0.014
	Average	0.002	0.005	0.004	0.004	0.008	0.014	0.015
50% AD-509	1	0.009	0.009	0.011	0.010	0.014	0.015	0.016
	2	0.005	0.005	0.005	0.005	0.008	0.014	0.016
	3	0.008	0.011	0.010	0.009	0.012	0.014	0.018
	4	0.005	0.006	0.006	0.006	0.011	0.015	0.014
	Average	0.007	0.008	0.008	0.008	0.011	0.014	0.016
10% AD-518	2	0.011	0.018	0.021	0.024	0.060	0.100	0.103
	1	0.010	0.016	0.019	0.020	0.043	0.076	0.081
	4	0.010	0.017	0.021	0.021	0.040	0.061	0.059
	3	0.011	0.016	0.019	0.021	0.043	0.073	0.073
	Average	0.010	0.017	0.020	0.022	0.046	0.078	0.079

* 0.78 percent alkali as Na_2O.

** Made and tested in accordance with ASTM C 227/CRD-C 123 (WES 1949).

Table 39

Length Change of Mortar Bars Made with 30 Percent Glassy Igneous Rock (CL-28 MS-1), High-Alkali Portland Cement RC-756(2),* and Different Amounts of Pozzolans**

Pozzolan	Bar No.	Length Change, %, at Ages Shown Below, days 7	14	21	27	56	90	105
No Pozzolan	3	0.097	0.256	0.316	0.342	0.425	0.442	0.442
	4	0.089	0.255	0.318	0.357	0.445	0.457	0.457
	1	0.088	0.257	0.316	0.342	0.449	0.455	0.455
	2	0.099	0.266	0.331	0.348	0.435	0.450	0.454
	Average	0.093	0.258	0.320	0.347	0.438	0.451	0.452
50% AD-505	2	0.004	0.013	0.014	0.013	0.014	0.021	0.023
	1	0.003	0.007	0.007	0.007	0.012	0.018	0.020
	3	0.002	0.008	0.007	0.007	0.015	0.020	0.022
	4	0.001	0.009	0.008	0.008	0.015	0.022	0.025
	Average	0.002	0.009	0.009	0.009	0.014	0.020	0.022
60% AD-509	4	0.006	0.009	0.010	0.009	0.013	0.018	0.020
	3	0.008	0.011	0.010	0.010	0.013	0.017	0.017
	2	0.006	0.009	0.006	0.006	0.010	0.016	0.019
	1	0.006	0.008	0.006	0.006	0.012	0.016	0.016
	Average	0.006	0.009	0.008	0.008	0.012	0.017	0.018
10% AD-518	3	0.026	0.153	0.212	0.258	0.374	0.400	0.412
	2	0.024	0.133	0.186	0.220	0.335	0.378	0.385
	4	0.024	0.143	0.207	0.239	0.356	0.383	0.382
	1	0.027	0.140	0.190	0.229	0.303	0.361	0.366
	Average	0.025	0.142	0.199	0.236	0.342	0.380	0.386

* 1.31 percent alkali as Na_2O.

** Made and tested in accordance with ASTM C 227/CRD-C 123 (WES 1949).

Table 40

Length Change of Mortar Bars Made with 3 Percent Opal (CL-4 G-1), High-Alkali Cement RC-756(2), and Different Amounts of Natural Pozzolan (AD-518)*

Admixture	Bar No.	Length Change, %, at Ages Shown Below, days					
		7	14	21	29	59	91
None	1	0.117	0.173	0.179	0.192	0.234	0.259
	4	0.089	0.146	0.155	0.157	0.179	0.214
	3	0.105	0.133	0.139	0.147	0.186	0.234
	2	0.124	0.178	0.182	0.193	0.231	0.258
	Average	0.109	0.158	0.164	0.172	0.208	0.241
5% AD-518	2	0.097	0.044**	0.151	0.159	0.217	0.255
	1	0.056	0.109	0.109	0.118	0.149	0.184
	4	0.069	0.118	0.123	0.135	0.184	0.208
	3	0.080	0.128	0.133	0.139	0.182	0.234
	Average	0.076	0.118	0.129	0.138	0.183	0.220
10% AD-518	3	0.087	0.115	0.120	0.128	0.208	0.250
	2	0.085	0.118	0.125	0.138	0.209	0.269
	1	0.074	0.114	0.118	0.135	0.224	0.279
	4	0.083	0.110	0.116	0.129	0.170	0.222
	Average	0.082	0.114	0.120	0.132	0.203	0.255
20% AD-518	4	0.018	0.012	0.014	0.013	0.024	0.037
	3	0.015	0.019	0.021	0.022	0.035	0.045
	2	0.012	0.022	0.019	0.019	0.033	0.044
	1	0.009	0.014	0.017	0.017	0.031	0.050
	Average	0.014	0.017	0.018	0.018	0.031	0.032
25% AD-518	3	0.003	0.009	0.010	0.012	†	
	4	0.044**	0.051**	0.051**	0.053**	†	
	1	0.004	0.008	0.011	0.010	†	
	2	0.002	0.007	0.007	0.010	†	
	Average	0.003	0.007	0.009	0.011		
30% AD-518	4	0.006	0.007	0.007	0.006	0.010	0.013
	1	0.008	0.009	0.010	0.009	0.012	0.014
	2	0.004	0.006	0.007	0.005	0.009	0.012
	3	0.005	0.007	0.009	0.007	0.011	0.013
	Average	0.006	0.007	0.008	0.007	0.010	0.013

* Made and tested in accordance with ASTM C 227/CRD-C 123 (WES 1949).

** This value not included in average.

† Testing stopped after the 29-day reading.

Table 41

Compressive Strength of Concrete and Mortar Made with Granite Gneiss (CL-14 G-1(B), CL-14 MS-1) and High-Alkali Cement RC-756(2)*

Specimen No.**	Age, days	Concrete Compressive Strength, psi†	Mortar Compressive Strength, psi††
B-1	7	3,130	
B-2		3,030	
Average		3,080	4,450
B-3	28	3,640	
B-4		3,750	
Average		3,700	5,510
B-5	90	4,210	(5,640, 56 days)
B-6		4,290	
Average		4,250	6,400
B-7	180	4,030	
B-8		4,260	
Average		4,150	6,000
B-9	365	3,720	
B-10		4,410	
Average		4,070	6,670

* 1.31 percent alkali as Na_2O.
** 3- by 6-in. cylinder.
† 0.49 water-to-cement ratio; ratio of cement to aggregate is 0.23.
†† 0.53 water-to-cement ratio; ratio of cement to aggregate is 0.44. Each value is the average of a pair of 2- by 2- by 2-in. cubes.

Table 42

Length Change of Concrete and Mortar Bars Made with Reactive Granite Gneiss and High-Alkali Cement RC-756(2)* at Two Temperatures

	Bar No.	Length Change, %, at Ages Shown Below								
		Days						Months		
		7	28	56	90	180	365	18	24	32
Concrete (CL-14 G-1(B),	1	0.004	0.009	0.009	0.011	0.021	0.025	0.044	0.061	0.052
CL-14 MS-1)	2	0.005	0.010	0.010	0.012	0.018	0.022	0.043	0.058	0.052
Stored at 100° F	3	0.004	0.013	0.013	0.013	0.021	0.025	0.058	0.067	0.061
	Average	0.004	0.011	0.011	0.012	0.020	0.024	0.048	0.062	0.053
Concrete (CL-14 G-1(B),	4	0.006	0.017	0.017	0.028	0.041	0.041	0.070	0.102	0.081
CL-14 MS-1)	5	0.009	0.021	0.022	0.034	0.037	0.057	0.082	0.120	0.101
Stored at 140° F	6	0.004	0.016	0.016	0.027	0.048	0.048	0.051	0.106	0.099
	Average	0.006	0.018	0.018	0.030	0.042	0.049	0.068	0.109	0.094

	Bar No.	Length Change, %, at Ages Shown Below								
		Days						Months		
		7	28	56	90	180	365	18	24	30
Mortar (CL-14 MS-1)	1	0.010	0.015	0.018	0.021	0.039	0.044	0.047	0.061	0.055
Stored at 100° F	2	0.010	0.015	0.018	0.021	0.038	0.042	0.047	0.061	0.056
	3	0.010	0.014	0.016	0.020	0.037	0.046	0.046	0.060	0.055
	4	0.010	0.015	0.017	0.021	0.039	0.045	0.045	0.062	0.056
	Average	0.010	0.015	0.017	0.021	0.038	0.044	0.046	0.061	0.056
Mortar (CL-14 MS-1)	1	0.012	0.012	0.018	0.028	0.036	0.065	0.061	0.094	0.077
Stored at 140° F	2	0.011	0.014	0.017	0.028	0.035	0.066	0.060	0.097	0.078
	3	0.012	0.013	0.018	0.029	0.034	0.064	0.060	0.095	0.076
	4	0.012	0.014	0.024	0.029	0.035	0.064	0.060	0.094	0.075
	Average	0.012	0.013	0.019	0.028	0.035	0.065	0.060	0.095	0.076

* 1.31 percent alkali as Na_2O. Concrete bars were 3 by 3 by 11-1/4 in.; mortar bars were 1 by 1 by 11-1/4 in.

Table 43

Length Change of Normal Size Mortar Bars Made Using Minerals Separated form Granite Gneiss

Fine Aggregate (CL-14 MS-1) with High-Alkali Cement RC-756(2)* at Two Temperatures

		Length Change, %, at Ages Shown Below								
		Days						Months		
	Bar No.	7	28	56	90	180	365	18	24	27
Quartz-Plagioclase Concentrations Stored at 100° F	1	0.012	0.014	0.022	0.022	0.024	0.039	0.050	0.049	0.046
Quartz-Plagioclase Concentrations Stored at 140° F	2	0.014	0.022	0.032	0.028	0.035	0.059	0.092	0.090	0.073
	3	0.014	0.021	0.033	0.029	0.035	0.060	0.094	0.085	0.074
	Average	0.014	0.022	0.032	0.028	0.035	0.060	0.093	0.088	0.074

		Length Change, %, at Ages Shown Below								
		Days						Months		
	Bar No.	7	28	56	90	180	365	18	24	27
Mica Concentrations Stored at 100° F	1	0.013	0.015	0.023	0.021	0.024	0.041	0.054	0.048	0.042
Mica Concentrations Stored at 140° F	2	0.018	0.022	0.034	0.031	0.038	0.064	0.099	0.089	0.074
	3	0.018	0.021	0.035	0.031	0.040	0.069	0.098	0.090	0.076
	Average	0.018	0.022	0.034	0.031	0.039	0.066	0.098	0.090	0.075

* 1.31 percent alkali as Na_2O; each bar was 1 by 1 by 11-1/4 in.

Table 44

Length Change of Small Mortar Bars* Made Using Minerals Separated from Granite Gneiss Fine Aggregate (CL-14 MS-1) with High Alkali Portland Cement RC-756(2)** at Two Temperatures

		Length Changes, %, at Ages Shown Below, days							
	Bar No.	7	14	21	28	56	90	180	365
Potassium Feldspar Concentration	1	0.000	0.036	0.026	0.033	0.022	0.033	0.033	0.033
Stored at 100° F	2	0.000	0.018	0.004	0.004	0.000	0.004	0.004	0.004
	3	0.004	0.011	0.000	0.004	0.004	0.004	0.004	0.011
	Average	0.001	0.022	0.010	0.013	0.009	0.014	0.014	0.016
Potassium Feldspar Concentration	4	0.007	0.015	0.004	0.004	0.004	0.007	0.004	0.015
Stored at 140° F	5	0.029	0.040	0.000	0.026	0.029	0.022	0.029	0.029
	6	0.015	0.029	0.007	0.026	0.033	0.018	0.026	0.033
	Average	0.017	0.028	0.004	0.019	0.022	0.011	0.020	0.026
Mica Concentration	1	0.018	0.022	0.022	0.022	0.014	0.014	0.014	0.014
Stored at 100° F	2	0.007	0.014	0.000	0.007	0.007	0.011	0.007	0.007
	3	0.000	0.004	0.011	0.000	0.018	0.014	0.018	0.018
	Average	0.008	0.013	0.011	0.010	0.013	0.013	0.013	0.013
Mica Concentration	4	0.025	0.033	0.018	0.022	-0.007	0.014	0.007	0.011
Stored at 140° F	5	0.014	0.014	0.014	0.022	0.000	0.000	0.018	0.018
	6	0.029	0.022	0.011	0.011	0.011	0.018	0.022	0.022
	Average	0.023	0.023	0.014	0.018	0.006	0.011	0.016	0.017
Quartz-Plagioclase Concentration	1	0.026	0.040	0.015	0.033	0.040	0.040	0.040	0.044
Stored at 100° F	2	0.000	0.017	0.000	0.010	0.000	0.010	0.000	0.000
	3	0.000	0.000	0.000	0.000	-0.002	-0.002	-0.002	-0.002
	Average	0.009	0.019	0.005	0.014	0.013	0.016	0.013	0.014
Quartz-Plagioclase Concentration	4	0.007	0.015	0.015	0.015	0.015	0.015	0.018	0.018
Stored at 140° F	5	0.033	0.051	0.029	0.036	0.047	0.058	0.033	0.055
	6	0.030	0.040	0.022	0.026	0.029	0.026	0.026	0.033
	Average	0.023	0.035	0.022	0.026	0.030	0.033	0.026	0.035

* 1/2 by 1/2 by 3-1/2 in.

** 1.31 percent alkali as Na_2O.

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